Keep Your Card in This Pocket

Books will be issued only on presentation of proper library cards

Unless labeled otherwise, books may be retained for two weeks Borrowers finding books marked, defaced or mutilated are expected to report same at library desk; otherwise the last borrower will be held responsible for all imperfections discovered

The card holder is responsible for all books drawn on this card

Penalty for over-due books 2c a day plus cost of notices

Lost cards and change of residence must be reported promptly.

THE SCHOOL DISTRICT OF KANSAS CITY, MISSOURI

Public Library
Kansas City, Mo.

Keep Your Card in This Pocket

THE ANTIQUITY OF MAN IN EUROPE

WORKS BY THE SAME AUTHOR

THE GREAT ICE AGE

AND ITS RELATION TO THE ANTIQUITY OF MAN.

With Maps and Illustrations. Third Edition, 1894.
[*Out of Print.*

PREHISTORIC EUROPE:

A GEOLOGICAL SKETCH.

With Maps and Illustrations. 1881.

OUTLINES OF GEOLOGY:

AN INTRODUCTION TO THE SCIENCE, FOR JUNIOR STUDENTS AND GENERAL READERS.

With 400 Illustrations. Fourth Edition, 1903.

SONGS AND LYRICS BY HEINRICH HEINE

AND OTHER GERMAN POETS, DONE INTO ENGLISH VERSE.

1887.

FRAGMENTS OF EARTH LORE:

ESSAYS AND ADDRESSES, GEOLOGICAL AND GEOGRAPHICAL.

With Maps and Illustrations. 1893.

EARTH SCULPTURE,

OR THE ORIGIN OF LAND-FORMS.

With Illustrations. Second Edition, 1909

STRUCTURAL AND FIELD GEOLOGY

FOR STUDENTS OF PURE AND APPLIED SCIENCE

With 79 Full-page Plates and 160 Illustrations in the Text. Third Edition, 1912.

MOUNTAINS: THEIR ORIGIN, GROWTH AND DECAY

With 81 Full-page Plates and 57 Illustrations in the Text. 1913.

THE ANTIQUITY OF MAN IN EUROPE

By JAMES GEIKIE, LL.D., D.C.L.

MURCHISON PROFESSOR OF GEOLOGY AND MINERALOGY IN THE UNIVERSITY OF EDINBURGH

Formerly of H. M. Geological Survey; Fellow of Royal Society; President of Royal Society of Edinburgh; Fellow of Geological and Mineralogical Societies of London; Past President of Royal Scottish Geographical Society. Hon. Member of Royal Physical Society; Geological Societies of Edinburgh and Glasgow; Literary and Philosophical Society of Manchester; Philosophical Society of York; Geologiska Foreningen, Stockholm; Videnskabs-selskab, Christiania; Deutsche Gesellschaft fur Erdkunde, Berlin; Société Belge de Géologie, etc. Société Neuchâteloise de Géographie; American Philosophical Society; New York Academy of Sciences. Corresponding Member of Academy of Natural Sciences, Philadelphia; Natural History Society, Boston; etc.

NEW YORK

D. VAN NOSTRAND COMPANY

TWENTY-FIVE PARK PLACE

1914

TO

HIS OLD AND MUCH ESTEEMED FRIEND

ROBERT MUNRO, Esq., M.A., M.D., LL.D., F.R.S.E., Etc.

FOUNDER OF THE MUNRO LECTURESHIP IN ANTHROPOLOGY AND PREHISTORIC ARCHÆOLOGY IN THE UNIVERSITY OF EDINBURGH, THIS VOLUME IS CORDIALLY INSCRIBED BY THE AUTHOR

PREFACE

SINCE I last essayed to review the geological evidence of the antiquity of man, the literature of the subject has greatly increased, and the most ardent student must find it hard to keep account of the constantly widening circle of knowledge. The research of the past twenty years has certainly cleared up much that was doubtful and obscure, and brought to light many interesting details which enable us to form a more adequate conception of the early history of our race than was previously possible. These later investigations, however, have not in any respect shaken the general conclusions arrived at twenty years ago, but, on the contrary, have served only to strengthen and confirm them. As the data multiply, it becomes more and more evident that the early history of our race is intimately connected with that of the Ice Age; and the conviction deepens that the period which witnessed the advent of man in Europe was distinguished by extraordinary climatic changes.

In the last edition of *The Great Ice Age* (1894), I ventured to correlate the Pleistocene accumulations

and to show how these evidenced a succession of cold and genial epochs. At that time it was possible to refer the oldest known relics of man—those, namely, of the Chellean stage—to the Second Interglacial epoch; the precise position in the geological succession of the later culture-stages, however, was still undetermined. Interglacial deposits had been recognised in many lands, but only a few of these could be with confidence assigned to special horizons. Fortunately, recent investigations—and more especially those of Professors Penck and Bruckner in the Alpine lands—have thrown welcome light on the subject, and the exact position and relative age of many of the more important interglacial deposits have now been definitely settled. The result of these investigations has been to confirm the view that the Chellean culture-stage dates back to the Second Interglacial epoch, and to prove that Mousterian man flourished during the Third Glacial and the succeeding interglacial epoch; while the geological horizons of the later culture-stages have also been more or less clearly defined.

The following lectures having been prepared for a mixed audience necessarily contain much elementary and explanatory matter. They make no pretension to be other than an outline sketch of a somewhat complicated subject, but they may serve to indicate the present position of geological opinion on the question of the antiquity of man.

I have to thank my colleague, Professor Bayley

Balfour, for the photographs of characteristic arctic-alpine plants, which appear in Plates VIII. to X., and Professor A. de Mortillet for kindly permitting me to borrow a number of illustrations of Palæolithic implements from his *Musée Préhistorique*. I am also under obligation to Messrs Blackie & Son for allowing me to reproduce from their *Natural History of Animals* a number of Friedrich Specht's admirable delineations, and to the editor of *Natur*, who has supplied a cliché of Paul Neumann's restoration of the Mammoth.

EDINBURGH, *March* 10, 1914.

LIST OF ILLUSTRATIONS

FULL-PAGE PLATES

ILLUSTRATIONS IN TEXT

MAPS

THE ANTIQUITY OF MAN

LECTURE I

THE TESTIMONY OF PLEISTOCENE FAUNAS AND FLORAS

Geological Estimates of Past Time are Indefinite. Oldest Authentic Human Relics are of Pleistocene Age. Doubtful Origin of the so-called "Eoliths." Discovery of supposed Primitive Types of Palæolithic Implements in Pliocene of England. The Testimony of Animals and Plants as to Climatic Conditions of the Pleistocene Period. Southern and Temperate Group of Mammals and Associated Plants and Molluscs. Tundra or Snow-loving Fauna and Contemporaneous Flora. Steppe Fauna and Flora. Climatic Changes of Pleistocene Period.

In the present course of lectures I purpose dealing with the question of the antiquity of the human race from a purely geological point of view. There are, as everyone knows, other points of view than this from which the subject has been considered. The researches of anthropologists and archæologists have thrown a flood of light upon the question, and left us in no doubt that the advent of man must be assigned to a very remote period. But at almost every step in their investigations they have been compelled to appeal to geological evidence in support of their

conclusions. They can tell us what kind of men lived in prehistoric times, but without calling in the aid of geology they can say little about his environment. They have shown us that the prehistoric occupants of Europe belonged probably to several races, and that these races exhibited different degrees of culture, the earliest comers being in many respects more primitive than their successors. But not a few of the results arrived at have been obtained by following geological methods of investigation. It is safe to say, indeed, that the successive stages in the history of the ancient peoples who flourished in Europe long before the dim beginnings of modern civilisation, have been established mainly by geological research. Not only so, but geology alone can tell us to what particular horizon in the long past the first appearance of man in our Continent must be assigned. Do not expect from geology, however, any precise statement as to the date of that interesting event. It is not at all likely, indeed, that the stony science will ever be able to tell us just how many years have passed away since then. Her answer to all inquiries of the kind will doubtless continue to be that of the old man in the ballad :—

> "I cannot tell, I do not know,
> But 'twas a long, long time ago."

And yet, as I hope to show in the course of these lectures, all the evidence points to the conclusion that our race has inhabited Europe for many thousands of years. Unfortunately, the evidence

that appeals most strongly to the geologist is not of a kind which others can readily appreciate. Should he venture to offer a rough estimate of the date in question, and admit at the same time that his estimate may be several thousand years beyond or under the truth, it is needless to tell him that computations so indefinite must be quite unreliable. A traveller who had painfully made his way across some trackless continental area, without maps or any means of measuring exactly the distance traversed, could not tell us precisely how many miles he had walked, but would nevertheless feel assured that the journey had been a very long one. The reality of a great distance covered would be just as patent to him as if his route had been carefully mapped and accurately measured. Even so is it with the geologist. Judging from what is known of the operations of nature in our own day—reasoning, in short, from the present to the past—he is convinced that the history of the human race cannot be comprised within a few thousand years. Impressed by the long succession of geological changes of which man has been a witness—the notable modifications of the surface brought about by denudation, the mutations of land and sea, the remarkable oscillations of climate, the revolutions of faunas and floras—the geologist is quite convinced of the great antiquity of man, even although he cannot give the precise date of his apparition.

The earliest human relics and remains, the

authenticity of which is beyond dispute, belong to that stage of geological history known as the Pleistocene period. Of late years, it is true, certain evidence has been adduced, which if substantiated would carry back man's advent to a much more remote date. I refer to the so-called "eoliths"—rudely fractured flints which, according to a number of excellent observers, show evidence of design, and are believed by them to be man's handiwork. That view, however, has not been generally accepted; many archæologists, indeed, would put it aside as entirely negligible. They can see no evidence of intelligent workmanship in the supposed implements, the breaking and chipping of which they attribute to natural causes. In weighing the conflicting statements and arguments of experts for and against the human origin of eoliths, the only conclusion one can reasonably come to is that of the judicious Sir Roger de Coverley—"there is much to be said on both sides." A Scottish jury's decision of "not proven" would seem indeed to meet the case. There is a geological side to the question, however, which cannot be ignored. It would appear that eoliths occur only in places where flint pebbles are commonly present, as in Tertiary gravel-beds of all ages. In such beds eoliths often abound, whereas in regions where flint gravels are wanting eoliths are similarly absent. This of itself, although not conclusive against the eoliths as artifacts, certainly inclines one to be sceptical. We may readily admit that the manu-

facture of true Palæolithic implements must have been preceded by that of simpler or more primitive types. Even the most conservative geologist has never questioned the possibility of very rude artifacts occurring in older deposits than Pleistocene river-drifts and cave-accumulations. But when he is asked to believe that artifacts of such a character occur not only in Pliocene, but in Miocene, and even in Oligocene and Eocene formations, he is naturally staggered. Since the Eocene period, which must date back several millions of years, the whole mammalian fauna has undergone manifold modifications and changes, continuous evolution having resulted in the more or less complete transformation of numerous types, while many others have long been extinct. And yet, if we accept the eoliths as proofs of man's existence in Eocene and Oligocene times, we must admit that in his case—and in his case alone—evolution must have been at a standstill during a prodigiously extended period. For it must be understood that the eoliths of the older Tertiary formations cannot be distinguished from those met with in Miocene, Pliocene, and even Pleistocene deposits.

It is quite possible, however, nay, it is even probable, that man was in existence in Pliocene times. Only the other day, indeed, Mr J. Reid Moir recorded the occurrence of human artifacts of pre-Palæolithic types in the Pliocene of England. Should this discovery be fully confirmed, our estimates of the antiquity of man must be greatly

increased. Mr Moir's announcement has not surprised geologists; but until the artificial character of the "specimens" in question has been established beyond doubt, we cannot assert that man lived in Europe before the Ice Age. (See NOTE 1.)

In the present course of lectures, therefore, our attention must be confined to the history of the Pleistocene period, during which man certainly occupied our Continent. The general succession of events that marked the passage of that period has now been fairly well ascertained, and even a rapid review of the geological changes—the climatic and geographical mutations—experienced by our race can hardly fail to convey some impression of its prolonged duration.

The investigator in this field of inquiry meets at the outset with certain difficulties, which do not often trouble those who study the records of very much older periods. It seems paradoxical, but is nevertheless true, that the history of so vastly remote an era as the Carboniferous, is in some respects more easily deciphered than that of the relatively recent accumulations of Pleistocene age. In the case of the Carboniferous we have an enormous thickness of strata, extending more or less continuously over thousands of square miles. The oldest deposits occur at the bottom of the series, and overlying these comes a great succession of strata, which may be studied, bed after bed, until we reach the topmost and youngest of the series. If, therefore, we have

skill enough to interpret the record, we can have no doubt as to the sequence of events. With Pleistocene accumulations — and more especially with those containing human relics and remains—it is quite otherwise. As a rule the latter never attain a great thickness, and seldom extend continuously over a wide area. They occur, in fact, as sporadic or isolated and often widely-separated patches, the relation of which, one to another, it might seem at first almost impossible to determine. It is only occasionally that we encounter a continuous succession of strata, from which the history of a long sequence of events can be extracted. But if Pleistocene accumulations are thus infrequently arranged in consecutive series, nevertheless we are not without evidence—often indirect, it is true, but sufficiently cogent notwithstanding—which enables us to surmount the difficulties of interpretation caused by the scattered and interrupted nature of the deposits.

If cave-deposits and river-alluvia containing human relics occupy no extensive areas, such is not the case with certain other accumulations of Pleistocene age. The well-known glacial formations often spread continuously over enormous tracts, and the tale they have to tell has a most direct bearing on that revealed by a study of the cave- and river-deposits—for both sets of accumulations belong to the same geological period. It is obviously important, therefore, that we should ascertain the precise relation of these several groups of formations to each other. The

history of one group we shall find practically involves that of all the others, and it matters little whether we begin our inquiry into the antiquity of man in Europe by studying the wide-spread deposits of the Ice Age, or by passing in review the testimony yielded by our cave-accumulations and river-drifts. Each line of investigation has its own advantages, but probably it will serve our purpose best to begin with the consideration of those cave-deposits and old river-alluvia from which have been obtained most abundantly the relics and remains of our ancient predecessors.

As an introduction to our proposed line of study, the present lecture will be devoted to the question of Pleistocene climate, so far as that is revealed by the character of the faunas and floras that were contemporaneous with prehistoric man. As these are for the most part still living species their evidence cannot be gainsaid. The conditions under which they flourish in our own day must afford an approximately true picture of Pleistocene times. Even the extinct species have something definite to tell us, their testimony supporting that of their still surviving congeners.

The Pleistocene mammals belong to three more or less well-marked groups, namely :—a Southern and Temperate Group, a Tundra or Snow-loving Group, and a Steppe Group. These several groups I shall consider seriatim, but shall at the same time have frequent occasion to refer to other types of

animal life, and to the contemporaneous plants of the period.

I. SOUTHERN AND TEMPERATE GROUP.—This group includes both existing and extinct types. Among the former are hippopotamus, at present confined to Africa, where its range has been considerably restricted within historical times, for it formerly abounded in the Delta of the Nile. A smaller species, it may be added, occurs in some of the rivers of western Africa. The remains of a large hippopotamus, which cannot be distinguished specifically from the present African form, lived plentifully in Pleistocene Europe, its range extending as far north at least as Yorkshire. A smaller species and even a dwarf type also flourished in southern Europe in Pleistocene times, their remains being specially abundant in some of the Mediterranean islands.

Several extinct types of elephant roamed over Pleistocene Europe. Of these the most notable was the southern elephant (*Elephas meridionalis*)—the largest of all the European species, attaining an estimated height at the shoulder of twelve feet nine inches. Another species was the straight-tusked elephant (*E. antiquus*), which ranged from north Africa over all central and western Europe as far north as Yorkshire. It is further notable that pigmy elephants—one species hardly exceeding three feet in height—were associates of the dwarf hippopotamus in Sicily and Malta.

Rhinoceroses of extinct species were not less prominent members of the Pleistocene mammalian fauna. Among conspicuous southern types that ranged from the Mediterranean into the British area were the relatively small Etruscan rhinoceros and the megarhine or broad-nosed rhinoceros (*R. merckii*).

The pachyderms I have mentioned could only have flourished under genial conditions. Their former presence in what are now temperate latitudes does not, however, indicate a sub-tropical climate, for they were associated with many mammals that still flourish in the forests and meadow-lands of Europe. Not a few of their congeners, it is true, are extinct, but among the living forms are red deer, roe deer, fallow deer, bison, wild boar, horse, beaver, and many others.

Among the carnivores, contemporaneous with that fauna, were a number of southern types, such as sabre-toothed tiger (now extinct), caffer cat (a native of Egypt and south Africa), serval (a south African species), spotted hyæna (a native of Africa, south of the Sahara, Plate I), striped hyæna (common in India, whence it ranges west as far as the Caucasus, Arabia, Syria, Palestine, and northern Africa), lion (at present confined to Africa and south-west Asia, although in historical times it had a much wider range). Other carnivores were various bears, wolves, foxes, martens, otters, etc. Many of the Pleistocene carnivores of existing species attained a larger size than their representatives in our day. Probably this was owing

THE SPOTTED HYÆNA (*Hyæna crocuta*).

to the favourable conditions under which they flourished—a genial, temperate climate, and a land well stocked with numerous herbivora.

The testimony of the Southern and Temperate group of Pleistocene mammals is strongly supported by that of the plants and land-shells. The evidence supplied by the flora, indeed, is even more convincing, and enables us to realise quite clearly the climatic conditions under which prehistoric man and his associates lived for a time in Europe. In certain Pleistocene deposits in Tuscany, for instance, we find a remarkable assemblage of plant remains—indigenous species being commingled with forms, some of which, although still living in Europe, are not now natives of Tuscany, while others are exotic, and yet others are extinct. Amongst these last are several known to have existed in Europe before Pleistocene times — they are survivals from the Tertiary. Along with these occurs the laurel of the Canary Islands, a variety of the common laurel. This plant does not now grow spontaneously in Italy, and was at one time believed to be an extra-European species. It still lives, however, near Toulon, on the French shores of the Mediterranean, where the orange is cultivated in the open air. It grows also near Blidah in Algeria, but its headquarters are the Canary Islands, where it flourishes luxuriantly in the woody regions with a northern exposure, between 1600 feet and 4800 feet above the sea — regions which, as Saporta remarks, are nearly always bathed

in steaming vapours, and exposed to the heavy rains of winter. During the greater part of the year the temperature keeps above 69° F., rarely falling in the winter months below 59° or 60°, and only on the coldest days reaching 49°. The common laurel and the beech are frequently associated in the Pleistocene of Tuscany, showing that they formerly grew side by side in that region. This, however, is no longer the case; the laurel demands more shade than it could find under present conditions, while the beech has retired to the northern flanks of the Apennines to obtain the fresh, cool climate now denied to it in the low grounds of Tuscany. In the same deposits occur a number of other trees which still characterise the flora of the Mediterranean regions.

Certain tufas of Provence have yielded a flora similar in all respects to that of the Tuscan deposits, save that the Tertiary and extinct species met with in the latter are absent. Among the plants of the tufas of Provence are the Canary laurel, which is associated with a number of species still indigenous to the neighbourhood. Commingled with these, however, are others no longer natives of Provence, such as Salzmann's pine, Pyrenean pine, and dwarf or mountain pine, which have abandoned the low ground of that region, and found refuge in the mountains. The same is the case indeed with certain other associated types which are now only met with in forest-clad hilly districts, and chiefly in situations with a northern exposure, where they can obtain

the requisite shade and coolness. We may note further that the Aleppo pine and the olive are entirely wanting in the tufas of Provence. These species obviously demand considerable summer heat rather than a humid climate, and are characteristic of the Mediterranean region to-day. Even the evergreen oak is absent, and very rarely occurs in any of the tufas of southern Europe.

Looked at broadly, the Pleistocene flora of southern France is most remarkable for the intimate association of still indigenous species with species which have ceased to be so—some of these last having retreated because unable to support the cold of winter, while others have retired to the mountains to escape the dryness of summer. The climate of southern France, therefore, like that of central Italy, must have been exempt from extremes—the winters were milder than now and the summers not so dry.

An examination of the plant-remains of Pleistocene tufas in northern France leads to similar conclusions. In the tufa of La Celle, not far from Paris, for example, we get a group of plants indicative of a former geographical distribution very different from that now obtaining. Among these are Canary laurel, fig-tree, box, and others, which no longer grow in the country round Paris. The Canary laurel, as already mentioned, exists in a wild state only in the most southern part of the Department of Var. The fig-tree is not indigenous north of Provence, while the box hardly passes north beyond Lyons. Mingled

with these and other southern forms are certain species that no longer live side by side with their former associates, although still common in central and northern France, some of them ranging into middle and northern Europe.

In this remarkable assemblage of plants we have evidence that a genial, humid, and equable climate formerly characterised northern France. The presence of the Canary laurel suffices to show that the winters must have been mild, for this plant flowers during that season, and repeated frosts would prevent it reproducing its kind. It is a mild winter rather than a warm summer which the laurel demands, and the same may be said of the fig-tree. That the summer in north France was more humid and not so hot as at present, is shown by the presence in the Pleistocene tufas of several species which cannot endure a hot arid climate, but flourish abundantly in the shady woods of northern France and Germany.

The tufas of Germany contain the remains of a flora that differs less from that of southern Europe in Pleistocene times than it does from the present flora of central Europe. Several of the species met with in the German tufas (as beech, lime, maple, sycamore, etc.) occur to-day in the Mediterranean region, but only in the mountains. In Pleistocene times, however, they lived upon the low grounds of central Italy. The German Pleistocene flora is distinguished from that of southern Europe, chiefly by the presence

of firs, and by the absence of the more southern forms, as vine, fig, judas-tree, laurustinus, etc. Nevertheless, nearly half of the species occurring in the Pleistocene tufas of Germany are common to the tufas of the low grounds of southern Europe. These facts would thus seem to indicate for central Europe more equable and humid conditions than the present, and it is remarkable that the Pleistocene flora of central Russia similarly implies a climate rather insular than continental.

So again the plant-remains yielded by certain Pleistocene deposits met with at high elevations in the Alps, have close affinities with a flora that flourishes to-day along the southern coasts of the Black Sea. When the Pontic alpine rose (*Rhododendron ponticum*) and its associates clothed the lofty mountain-slopes of the Inn Valley, the climate could not have been less genial than that experienced at present upon the flanks of the Alps in Italy. These Italian Alps were likewise favoured with somewhat more clement conditions than they now enjoy. The vine then grew, as it still does, along the banks of Lake Iseo, the box abounded, the chestnut flourished at an elevation of 2600 feet, and the Pontic alpine rose—now no longer an alpine plant—was very widely distributed.

Without going into more details of the evidence furnished by the flora, enough has been advanced to justify the conclusion that during some stage of the Pleistocene period the climate differed considerably

from that of the present. It was essentially oceanic or insular. The summers and winters were not so strongly differentiated as they are now. The climate, in a word, was milder and more equable.

I must not omit to mention that the same conclusions may be drawn from the character of the shells which occasionally appear in large numbers along with plant-remains in Pleistocene tufas. In the tufa of La Celle, near Paris, for instance, about fifty species of shells occur, most of them still living in the district. Others, however, have retired from that district, although met with elsewhere in France; yet others, no longer natives of France, are found elsewhere in Europe. Lastly, several extinct or entirely exotic species have been recognised.

Among the emigrated species, some have retired to the hillier parts of France, while one is not now a native of western Europe, but flourishes over wide regions in eastern and north-eastern Europe. The most notable of the extinct forms is a zonites, belonging to a group foreign to northern France and similar latitudes in our Continent. The two forms to which it most nearly approaches are natives, the one of Austrian Tyrol and the other of Croatia.

The geographical distribution of the shells, so different from the present, and the former wider diffusion of certain forms, lead to the conclusion that the climate of northern France was formerly more equable, so as to permit species, now widely separated, to live together. That it was also a humid climate

FIG. 1.—THE NORWEGIAN LEMMING (*Myodes lemmus*).

FIG. 2.—JERBOA (*Alactaga jaculus*).

[To face page 16.

is indicated by the general facies of the shells, nearly all of them land-shells, and the large majority such as live in damp and shady places.

Certain German tufas have yielded a similar assemblage of shells, and thus tell the same tale as the French tufas. The Pleistocene alluvia of many other parts of Europe now and again contain fresh-water shells, some of which no longer live in the districts where these alluvia occur, but in more southerly or south-easterly regions. It is needless, however, to go into greater detail, for again and again the facts point to the same conclusion—namely, that during some part of the Pleistocene period the climate was more genial and equable than now. Clement winters and cool summers formerly permitted the wide diffusion and intimate association of plants which to-day have a very different range. Temperate and southern species (as ash, poplar, sycamore, fig, judas-tree, etc.) overspread all the low grounds of France as far north at least as Paris. It was under such conditions that elephants, rhinoceroses, and hippopotami, and vast herds of deer and wild cattle ranged over Europe, from the shores of the Mediterranean up to the latitude of Yorkshire, and probably even farther north still; and from the borders of Asia to the Western Ocean. (See NOTE 2.)

II. TUNDRA OR SNOW-LOVING GROUP.—We may now turn our attention to another series of mammals which has a very different tale to tell us—the tundra or snow-loving group. I think we shall better

understand their testimony and that of the contemporaneous flora, if we first endeavour to have a clear conception of what is meant by tundra conditions. Geologists can only interpret the past by constant reference to the present, and I make no apology, therefore, for a rapid sketch of those regions of the globe where tundra conditions prevail.

The arctic lands of Eurasia and North America show two well-marked zones — a zone of treeless wastes bordering the Arctic Ocean, and a coniferous forest zone lying immediately to the south. The treeless wastes are known as tundras in Europe and Asia, and as "barren grounds" in North America. These form plains of immense extent, but of very unequal width from north to south. In Eurasia they lie for the most part north of the Arctic Circle, while in North America they range upon the whole considerably farther south, reaching the 60th parallel on the western shores of Hudson Bay. Their southern boundary, however, is in both Old and New Worlds exceedingly irregular. Where the flat lands are exposed to the full sweep of the northern blasts, tundra conditions advance far to the south, invading the forest-zone in narrower or broader stretches. Indeed, even within the region of arctic forests isolated patches and wider areas of tundra are encountered. In other places more sheltered from the fierce winds coming from the polar seas, the arctic forests in their turn encroach upon the tundras, so as nearly to reach the shores of the

PLATE III

THE ARCTIC FOX (*Canis lagopus*).

frozen ocean. Such is the case in the valleys of the Yenesei, the Khatanga, the Olenek, the Lena, and other north Siberian rivers. Similarly, in North America the arctic forests straggle down the valleys of the Mackenzie and other rivers to beyond the Arctic Circle.

Mosses and lichens form the prevailing vegetation of the tundras—marshes and bogs extending over vast areas in spring and summer, while the less marshy tracts are carpeted with grey lichens. Here and there, too, in sheltered spots, dwarf birch and willow-scrub sprinkle the surface or flourish in denser masses, and ever and anon more or less wide stretches of meadow put in an appearance. Now and again the interminable plains give place to rolling ground, the low hills and knolls being not infrequently clothed with dwarf trees. No hard and fast line, indeed, can be drawn between the tundras and the arctic forests. The two regions not only interdigitate, but numerous oases of trees are encountered in the tundras along their southern margin, while equally numerous patches of tundra, as already mentioned, are met with farther south within the forest zone. It may be added, that in northern Siberia bare rocky hills and mountains—highly fissured, and showing many gullies, ravines, and debris-strewn valleys—now and again break the uniformity of a tundra landscape.

A word or two now as to the characteristic animals of the tundras and barren grounds. First among

these come the lemmings (Plate II, 1). They feed on grass-roots and stalks, mosses, reindeer-lichens, and the shoots of the dwarf birch, for which in winter they tunnel through the turf or under the snow. The banded lemming is an especially characteristic form, since it is confined to the maritime tracts of Eurasia and the adjacent islands, and the corresponding areas of North America, and is never met with in the forest-zone. The Obi lemming has a similar distribution, but ranges somewhat farther south, and not quite so far north, as the banded lemming. The arctic fox (Plate III) is another characteristic member of the tundra fauna, having a high northern range. It occasionally wanders south to the 60th parallel, but that is only in treeless regions, for it everywhere avoids the forests, seeming to prefer the barest and most sterile lands. Another common denizen of the tundras is the arctic or mountain hare. This is the same species so commonly met with above the limits of the forests in the mountains of temperate Europe. A closely allied form (polar hare) frequents the barrens of North America. The reindeer must also be included in the tundra fauna, although in winter it ranges far into the forest-zone. The musk-ox (Plate IV), formerly a native of Eurasia, is now confined to North America. Like the arctic fox it avoids the forests, ranging north of these from the 60th parallel up to the highest latitudes.

Such are the most characteristic mammals of the tundras. There are many other animals, however,

THE MUSK OX (*Ovibos moschatus*)

which frequent the same regions, more especially in summer. Among these may be mentioned glutton, voles, ermine, weasel, wolf, common fox, and brown bear. The summer visitors also include a vast host of birds, especially water-birds.

The climate of all these northern plains is extreme—the winter temperature falling upon an average to 27° below zero, while in summer the average temperature is about 50° F. The actual range in certain regions is of course considerably greater. These conditions necessarily give rise to annual migrations. Only a few mammals brave the long winter of the tundras, when river and lake are often frozen solid, and the whole land is sheeted in snow. During the great frosts the air is remarkably still, but as winter draws to a close, storms of wind and snow become frequent. Wide regions are then often swept bare, and the snow is blown into every abrupt hollow and depression in the plains, and into the gullies and ravines of the hills, where it becomes so beaten as often to bear the weight of a man. Not only snow, but sand and dust, are thus swept forward. The sand and dust are no doubt largely obtained from the great river-valleys and deltas, but no inconsiderable proportion is derived also from the bare rocky hills and mountains, which in many places diversify the surface of the circumpolar plains. Frost is a great pulveriser of rocks, not only splitting them into fragments, but disintegrating their surfaces into grit, sand, and dust. It is remarkable how in the

highest northern latitudes the surface of the snow often becomes discoloured with fine sand and dust derived in this way from exposed rock-surfaces.

Having now glanced at the climatic conditions of our existing tundras and the character of their fauna, I may refer shortly to the wide distribution of that fauna in Pleistocene Europe. Two of the most characteristic tundra forms, as we have seen, are the banded and the Obi lemmings. Now remains of both these species have been met with again and again over all central Europe—in Russia, Poland, Austria-Hungary, North and South Germany, northern Switzerland, France, Belgium, and England. Sometimes they occur in single specimens, at other times they are extremely numerous, the remains of several hundreds having been obtained at various localities. In many places both species of lemmings are found together; elsewhere either one or other may occur alone. The banded lemming, as a rule, has left its remains most abundantly in hilly and upland tracts, while those of the Obi lemming are met with more frequently in low-lying areas—a distribution quite in keeping with that which obtains at present in the tundras. That these arctic animals were not mere passing or occasional visitors is shown by the fact that young and full-grown individuals occur together in hundreds at various places, and are associated with the remains of other characteristic arctic animals which bred in the same regions. Thus well-preserved skeletons of arctic fox, having their

THE GLUTTON (*Gulo borealis*).

milk-teeth, have been found lying side by side with the bones of the lemmings. As the arctic fox breeds in June, it is obvious that those young individuals must have died in summer.

Our knowledge of the former distribution of the arctic lemmings is no doubt not so full as it will yet be, but already we have ascertained that these creatures ranged as far south as central France and the base of the Alps, in Switzerland, and as far west as Somerset, in England. Besides the arctic fox, many other northern forms were congeners of the lemmings in middle and western Europe, such as mountain hare, musk-ox, reindeer, glutton (Plate V), various voles, ermine, weasel, wolf, common fox, ibex (Plate VI), and the now extinct mammoth (Plate VII) and woolly rhinoceros. A number of northern birds have also been recorded from the same deposits as those which have yielded relics of the tundra animals. I need mention only ptarmigans, buntings, snow-owls, ducks, geese, and swans—all of which are in harmony with the arctic character of the mammals, since the same forms are in our day constant summer visitants in the circumpolar treeless lands. The arctic fauna does not seem to have found its way into Italy, but true alpine species—ibex, chamois, alpine hare, and marmot—then ranged far south in the peninsula.

We may note further that just as there is evidence of the former occupation of middle and western Europe by an arctic fauna, so we have abundant traces in the same regions of a well-marked arctic flora. High

northern species of mosses, polar willow (Plate VIII), dwarf birch (Plate IX), mountain avens (Plate X), and various other northern plants have been met with in superficial deposits over a very wide area, extending from southern Sweden and England across middle Europe to the foot of the Alps.

We cannot doubt, therefore, that true tundra conditions have formerly prevailed at relatively low latitudes in Europe. The wide-spread distribution of the arctic animals and plants just mentioned points clearly to that and to no other conclusion. We may, therefore, reasonably infer that the climate of middle Europe must at one time have approximated in character to that of northern Siberia—the seasons being doubtless strongly contrasted, and thus compelling annual migrations. With the advent of summer the home of the arctic lemmings was invaded by troops of visitants—by mammoth, woolly rhinoceros, wild horse, saiga-antelope, and many others, and by numerous birds. An arctic-alpine vegetation clothed the low grounds, which in the warm season doubtless showed wide stretches of bog and marsh and many shallow lakes. Here and there flourished patches and wider tracts of birch and willow-scrub, but the land was practically treeless. Man, we know, was an occupant of middle Europe at this time. Perhaps, like the mammoth and the woolly rhinoceros, he may have been rather a summer visitor than a constant denizen, departing for more clement regions at the approach of winter. We shall probably not err in

PLATE VI

THE ALPINE IBEX (*Ibex albinus*).

THE MAMMOTH (*Elephas primigenius*). Restoration by Paul Neumann. From "Natur," by permission.

supposing that the winter would have much resemblance to that now experienced in northern Siberia—long spells of still weather with intense frost, interrupted now and again (especially at the changes of the seasons) by fierce snowstorms, in which the wild animals could hardly fail occasionally to perish in large numbers.

III. Steppe Group.—We come next to consider the steppe group of mammals, and as I have prefaced my account of the tundra group with a short sketch of the conditions that obtain in circumpolar regions, I may now take a similar brief glance at the steppe lands of Europe and Asia. The regions included under this head show considerable variety. Some steppes are mere desert wastes, while others are fertile tracts capable of high cultivation. Many are low plains, others are elevated plateaus—the former having a sub-arctic, the latter a sub-tropical climate; and between low and high steppes many gradations are met with. All are more or less characterised by an extreme range of temperature. The steppes with which we are at present concerned, however, are the generally low grassy plains known as the sub-arctic steppes. These occupy wide areas in south-east Russia and south-west Siberia, extending between the middle course of the Volga and that of the Irtysch. It is quite a mistake to suppose that these steppes are throughout all their extent treeless plains. In many places chains and irregular groups of hills diversify the surface, while here and there trees of

various kinds, such as pine, larch, birch, oak, lime, alder, willow, wild-apple, and others, are more or less plentiful. Many of the woods are mere oases, extending along the banks of rivers and streams, or clustering round the margins of fresh-water lakes. In south-east Russia the boundary between the steppes and the forest lands is very irregular—the two regions constantly interdigitate.

The climate of the sub-arctic steppes is quite continental—the summer being relatively warm, and the winter relatively cold. The average temperature in January hardly exceeds 30° F., while that of July is at least 70°. Again, the rainfall is very uncertain. In some years it is excessive, in others meagre, while occasionally it fails altogether. With the approach of spring vegetation rapidly develops, becoming rank and luxuriant, but with the heat of summer it quickly fades and withers away. Severe frost, and frequently heavy snowstorms, characterise the winter. In such areas as are more or less wooded, the climate is somewhat less continental—the summers being relatively less dry, and the winters not so cold. But even in those wooded regions the seasons are strongly contrasted. In general, we may say, the steppe lands in summer are practically rainless. The ground is thus parched and burnt up, so that sand and dust rise with every wind: and as the open plains are often swept by summer storms, vast quantities of loose materials are transported from place to place, and here and there accumulate in

PLATE VIII

POLAR WILLOW (*Salix polaris*) surrounded by Herbaceous Willow (*S. herbacea*). From the Rock Garden, Royal Botanic Gardens, Edinburgh.

Photo: Professor Bayley Balfour.

hollows and depressions, or come to rest in the lee of sheltering rocks and hills. In winter, if little snow has fallen, the unprotected ground is similarly scoured by tempests—dust, sand, and even small stones being carried forward. Thus, both in summer and in winter sand- and dust-storms play an important rôle, and loose materials are piled up to great depths in valleys, and in the ravines, fissures, and crevices of the rocky hills.

As a rule these heaps and sheets of drifted sand and dust show little or no arrangement, although now and again some trace of bedding may appear. Should they chance to become well covered with snow in winter, then, when warmth returns and the snow gradually melts away, plants quickly spring up, and the heaps become fixed and cease to drift. It is obvious that not infrequently land-shells, and often enough the remains of mammals, must be entombed in such wind-blown materials.

In winter, however, it is snow more commonly than dust that drifts before the wind. The great snowstorms of the sub-arctic steppes are quite as terrible as those of the tundras. No life can withstand the fury of the blizzards, and many are the disasters on record. In 1827, for example, all the flocks and herds that wandered over the steppes between the Volga and the Urals perished in one great storm. According to the Government Report the loss sustained by the Kirghiz amounted to 10,500 camels, 280,500 horses, 30,480 cattle, and

1,012,000 sheep. Not many years pass without some disaster of this kind, and when the snow has melted away, hundreds of cattle, often far strayed, may be found huddled together in one place—some suffocated, frozen, or starved to death, others drowned in the creeks and ravines in which they had vainly sought for refuge from the blast. Now we can readily conceive how the carcasses might eventually be buried under drifted sand and dust, and the bony skeletons thus become preserved for an indefinite period.

Among the most characteristic animals of the sub-arctic steppes are jerboas (Plate II, 2), pouched marmots, bobac, pika or tailless hare, small hamster rat, various voles, corsac, caragan fox, manul cat, saiga-antelope (Plate XI), dzeggetai (Plate XII), wild horse, etc. Besides these, many other animals are met with in the steppes, but are hardly so characteristic, since they range into adjacent regions, to which they more properly belong. Amongst them may be mentioned lynx, wild cat, tiger, wolf, jackal, common fox, martens, ermine, weasel, otter, glutton, badger, brown bear, beaver, common hare, mountain hare, wild boar, elk, reindeer, roe-deer, stag, etc. Several hundred species of birds frequent the steppes, among which may be mentioned great and little bustards, larks, grouse, buzzards, eagles, owls, etc.

All the animals already mentioned as most characteristic of the sub-arctic steppes are represented in the

DWARF BIRCH (*Betula nana*).
From the Rock Garden, Royal Botanic Gardens, Edinburgh.
Photo: Professsor Bayley Balfour.

[*To face page* 28.

caves and alluvial deposits of west and middle Europe. Jerboas, pouched marmots, bobacs, and marmots (Plate XIII), tailless hares and others, all formerly flourished in those latitudes. Besides these most characteristic steppe animals, occurred many other forms which were not restricted to steppe lands, such as mammoth and woolly rhinoceros, marsh-lynx, cave-lion, hyæna, wolf, common fox, ermine, weasel, badger, reindeer, urus, bison (Plate XIV), etc. Many birds also were present—all of them species which in our own day frequent the steppes of south-east Russia. Land-shells are also very often found in less or greater abundance along with the relics of the steppe animals just mentioned, most of the shells representing forms that now live in dry steppes, while some are natives of wooded regions.

The plant-remains associated with relics of the steppe fauna are quite in keeping with the latter, but are upon the whole seldom met with, the conditions not being favourable to their preservation. Trunks and branches of trees occur very rarely, the most common remains being a few thin layers and seams of peaty matter, apparently consisting chiefly of grasses. Nevertheless, we need have no doubt that a steppe flora formerly flourished in middle Europe, for (as Engler, Ascherson, Petry, and other botanists have shown) many well-known steppe plants survive in the existing flora of that region.

Among the animals associated with the true steppe forms were some which, as we have seen,

invaded central Europe in tundra times. Of these perhaps the most notable are the mammoth and the woolly rhinoceros. Probably they were only summer visitors, but under steppe conditions they became truly indigenous and very abundant. The broad valleys and open spaces of central Europe were at that time treeless plains, although woods seem to have existed here and there, especially along the margins of lakes and streams. The climate, we need not doubt, was much like that of the sub-arctic steppes of south-east Russia and south-west Siberia, regions which, like the tundras, are much exposed to wind action. We may be sure, therefore, that while dry steppe conditions prevailed throughout central Europe, dust-storms and snowstorms must have been of common occurrence. We have seen how in existing tundras and steppes the semi-domesticated and wild animals of those regions are now and again overwhelmed in storms and smothered in snow. Similar catastrophes, it may well be believed, must have happened again and again in the tundras and steppes of prehistoric times. And we are not left in this matter to mere conjecture, for the carcasses of some of the more notable animals of those days, now extinct, have been preserved to the present in the frozen snows—the famous ice-formations of northern Siberia. So perfectly preserved, indeed, was the mammoth discovered by Mr Adams, that its flesh was devoured by wolves and bears, and from the appearances presented by

MOUNTAIN AVENS (*Dryas octopetala*). From the Rock Garden, Royal Botanic Gardens, Edinburgh.

Photo: Professor Bayley Balfour.

[*To face page* 30.

it and others, we cannot doubt that the animals had perished in snow-drifts. Brandt records, for example, that the congested veins and capillary vessels in the head of a rhinoceros examined by him were charged with coagulated blood, as if the animal had died of suffocation; and Schrenck says of another described by him, that the distended nostrils and gaping mouth were highly suggestive of a similar death. It is probable that these animals were summer visitors to the tundras, overtaken by autumnal snowstorms. If perfectly preserved carcasses are rare, such is not the case with skeletal remains. In many places throughout Siberia the bones of various mammals occur in enormous quantities, huddled together, as it were, in very limited spots. It seems impossible to account for such hecatombs on any other supposition than that they are the silent records of great blizzards. Even in our own time herds of wild reindeer, with their young, are overcome by snowstorms in the tundras, while in North America great flocks of sheep and cattle frequently perish in the same way. Professor Garman, who has drawn attention to the disastrous results of blizzards in the great prairie lands of that region, is of opinion that the extraordinary heaps of skulls and other remains of the bison that are met with here and there in northern Colorado and Wyoming, are the remains of herds which have been suffocated in snow-drifts.

It is not necessary to suppose that all the relics and remains of the mammoth and its congeners in

Siberia are evidence of the destructive effect of blizzards. The animals doubtless met their death under many different circumstances. Sometimes they would appear to have been bogged in swampy holes and morasses. I have referred to the peculiar ice-formations of the arctic coast-lands. These are sheets of ice of unknown thickness, preserved under more or less thick accumulations of earthy and loamy materials. The ice is believed to represent the blown or drifted snows of prehistoric times, which here and there have been protected from complete dissolution by soil and subsoil flowing over and accumulating upon them, under the influence of thaw, in spring and summer. Such movements of superficial materials are indeed of common occurrence in high latitudes at the present day. The surface of the buried ice-strata is very uneven, being furrowed and trenched by deep ruts and hollows. These depressions are filled up with frozen mud, etc., containing vegetable debris and abundant mammalian remains, including those of mammoth and woolly rhinoceros. Probably a large number of the bones may simply have been introduced into the hollows by the flowing soil in spring—they may have been lying originally scattered over the surface. In other cases, however, the animals themselves seem to have fallen or sunk into the depressions. All the evidence leads to the inference that in the warm season these high northern regions were visited abundantly by mammoths, rhinoceroses, horses, bisons, wapiti, and

THE SAIGA ANTELOPE (*Saiga tartarica*).

[*To face page* 82.

others. Such being the case, it is not hard to understand how the bulkier animals might now and again become trapped in the treacherous bogs and subjacent muds that covered and concealed the ice-formations and their deep clefts and depressions.

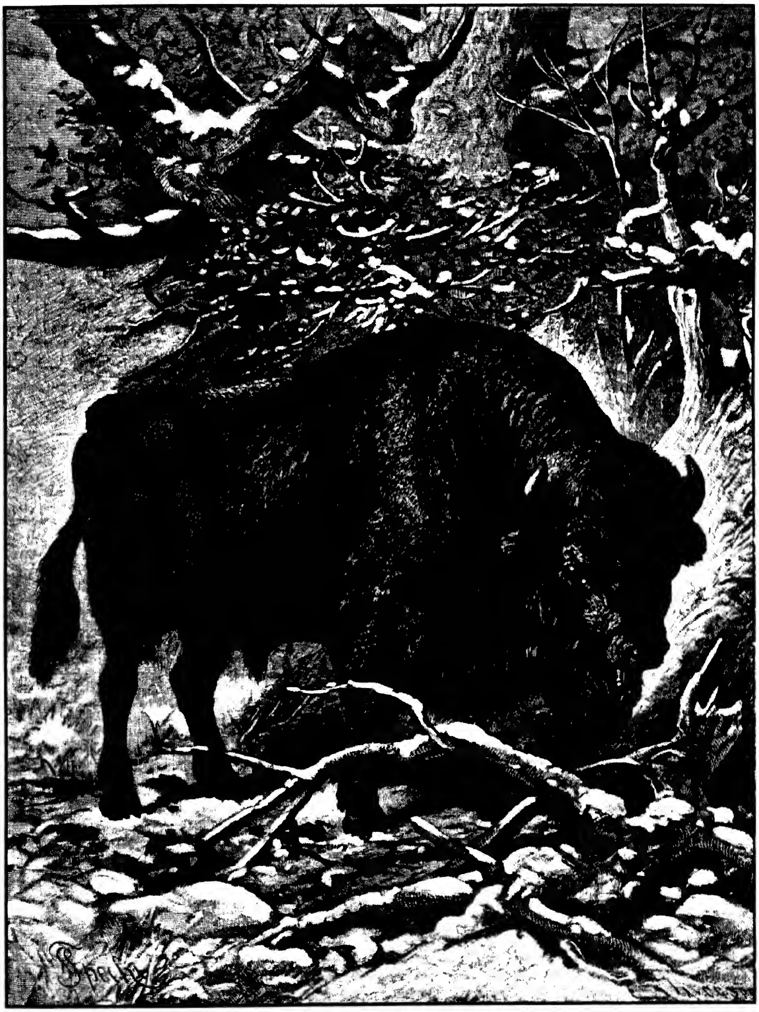
Thus a general review of the evidence afforded by the animals and plants that lived in Europe during Pleistocene times leads to the conclusion that the period in question was characterised by very considerable changes of climate. The theory of great annual migrations, formerly advanced to account for the presence of southern, temperate, boreal, and arctic types of mammals in the Pleistocene of Europe generally, can no longer be sustained. Even if we could suppose it possible that hippopotami and reindeer might have wandered to and fro across the whole breadth of our Continent in one season, we must admit that no migrations can account for the strongly contrasted floras which have left their remains in the Pleistocene deposits of northern, central, and southern Europe. They at least could not have indulged in such feats of travel.

Now a wide-spread and decided change of climate does not take place suddenly—a revolution of the kind affecting a whole continent can only be very gradually accomplished. In subsequent lectures I shall adduce evidence to show that the climatic changes of the Pleistocene were carried on through a long series of ages—that there was no abrupt transition from one kind of climate to another. For

the present, however, we have not got beyond the threshold of our inquiry—all I have tried to show is the fact that prehistoric man lived through a succession of climatic revolutions. That, then, may be taken as our first argument in favour of the great antiquity of the human race. When we reflect on the simple fact that no marked change in the physical conditions of the Old World has been effected within historical times, we are prepared to believe that the strongly contrasted climates of the Pleistocene must have extended over many thousands of years. Most of the more or less local climatic changes or modifications brought about within historical times have resulted from the action of man himself. The wholesale destruction of forests, the draining of swamps and marshes, the planting of trees have all doubtless had their effect. But we have no reason to believe that the average temperature of Europe has either risen or fallen since the earliest times of which any written records have been preserved. (See NOTE 3.)

THE MARMOT (*Arctomys marmota*).

[To face page 34.



THE BISON (*Bison europæus*).

[*To face page* 34.

LECTURE II

THE TESTIMONY OF THE CAVES

Archæological Stages of Culture: Palæolithic, Neolithic, Bronze, and Iron Ages. Types of Palæolithic Man. Origin of Caves. General Character of Cave-deposits containing Relics of Prehistoric Man. Kent's Cavern and Brixham Cave—their Testimony as to the Contemporaneity of Man and the Pleistocene Fauna, and the Prolonged Duration of Pleistocene Times.

In the preceding lecture I discussed the subject of Pleistocene climate. Confining attention exclusively to the evidence of faunas and floras, I showed that their testimony put it beyond doubt that the Pleistocene period was characterised by profound climatic revolutions. Such revolutions necessarily imply the lapse of a very long time, and as prehistoric man was certainly a witness of them, the great antiquity of our race must be admitted. From the evidence I have adduced we cannot, it is true, arrive at any definite conclusion as to the absolute length of the Pleistocene period. So far as we have advanced in our inquiry, all we can be sure of is its prolonged duration. We are almost wholly ignorant of the causes which induce climatic changes on such a grand scale as those we have been considering. Nevertheless, we are not without evidence of a

more definite character which, so far as it goes, gives some precision to our conception of Pleistocene time. The deposits containing human relics and remains have yielded certain data, which may eventually enable us to form tentative estimates of the duration of the period in question. Of the deposits referred to some occur in caverns, while others appear at the surface as alluvial or subaërial accumulations. To the study of these records of the past I shall presently draw your attention, but before doing so I may very briefly sum up what archæology has to tell us about the relics of Pleistocene man and their classification. That classification is based chiefly on the characters of implements and ornaments, and prehistoric time has been divided into three periods, termed respectively the Stone Age, the Bronze Age, and the Iron Age.

Of these the earliest is the Stone Age, when implements and ornaments were fashioned exclusively of stone, horn, and bone. The use of metals for such purposes was then unknown. To the Stone Age succeeded the age of Bronze, at which time cutting-instruments, such as swords, knives, and axes, began to be made of copper, and an alloy of that metal and tin. When in the course of time iron replaced bronze for cutting-instruments, the Bronze Age came to an end and the Iron Age supervened. This classification has received the strongest support from independent geological investigations, and has long been generally accepted.

These archæological periods are doubtless just so many phases of civilisation, and it is conceivable that Stone, Bronze, and Iron Ages may have been contemporaneous in different parts of one and the same continent. Although there is nothing improbable in such a supposition, it has nevertheless been well ascertained that, so far as Europe is concerned, a true Stone Age to which the use of metals was altogether unknown endured throughout our Continent for a prolonged period. And it has likewise been proved that after the knowledge of bronze had become general in Europe, our ancient predecessors continued through many centuries ignorant of the use of iron.

The close of the Stone Age was not marked by the total abandonment of stone for bronze artifacts, for stone continued to be used for some kinds of implements well into the Bronze Age, and even down to historic times. The substitution of metal for stone cutting-implements might have been very slowly effected in some parts of Europe: and one can readily believe that in certain countries bronze might come to be almost exclusively employed for such purposes, while elsewhere it remained much longer either only partially in use or quite unknown. One can hardly doubt, for instance, that long after the natives of southern Europe had commenced to attack their enemies with bronze swords and daggers, and to decorate their own persons with trinkets of the same alloy, the inhabitants of the secluded mountain-valleys of Scotland and the outlying islands might

still be living in a Stone Age. It is very improbable, in a word, that there was any abrupt transition from an age in which only stone implements were used to one in which bronze was exclusively employed. Further, we cannot infer that the Stone and Bronze periods of one country are necessarily strictly contemporaneous throughout with the similar stages in the archæological history of all other parts of Europe. The closing scenes of the Stone Age in north-west Europe may be synchronous with the beginning of the Bronze period in the south-east of the Continent. This would necessarily follow if it be the case, as many believe, that the knowledge of metals came from the East. The difference in point of antiquity, then, between the commencement of the Bronze Age in two such countries as Greece and Britain, let us say, would simply be measured by the length of time the natives of the latter country remained ignorant of bronze after the former had come to know it. But that time, however long it may have been, is too trifling to be taken into consideration, when periods of such duration as those of prehistoric archæology are being dealt with. Moreover, the passage from the true Stone Age into the Bronze Age may have been actually sudden, if, as is not unlikely, metallurgical knowledge came in with one of those great folk-waves which have successively swept over Europe. But however that knowlege was acquired, it is certain that, long after cutting-instruments of bronze had come into use in every part of our Continent, stone

artifacts continued to be employed for many purposes, and are found commingled with relics of bronze in the "finds" that belong to that period.

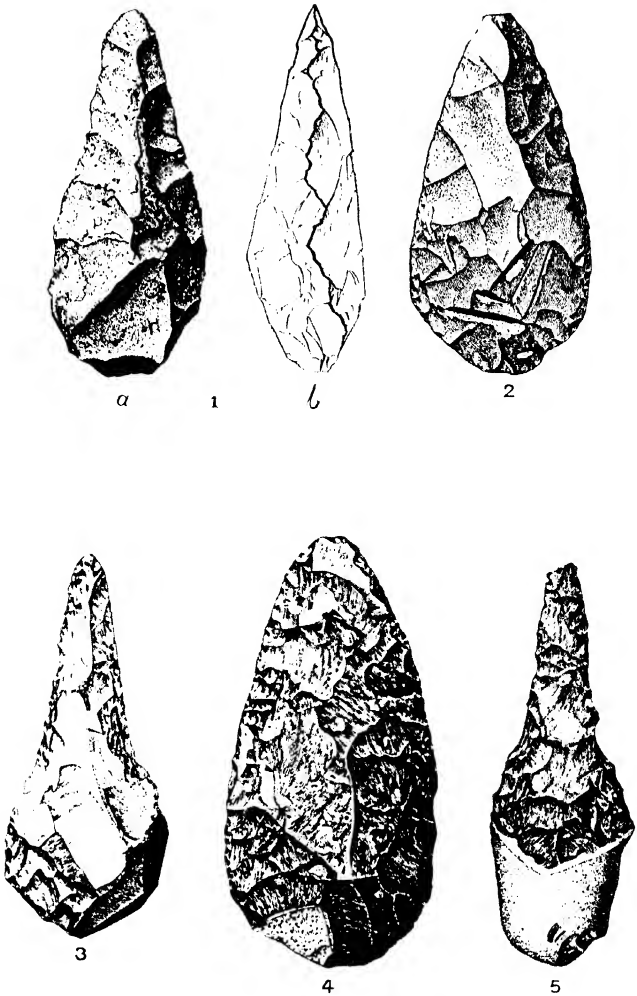
With the Bronze and Iron Ages, however, the geologist has but little to do. No great revolutions of climate or geographical conditions have supervened in Europe since the close of the true Stone period. That period of archæological history comprises two subdivisions, namely, the Palæolithic or Old Stone Age, and the Neolithic or New Stone Age. The stone implements pertaining to the former, however rudely fashioned or well-finished they may be, are merely chipped into shape, and never ground or polished. The stone weapons and instruments of the later age, on the other hand, are often finely worked, being frequently ground to a sharp edge or point, or polished all over. But the general simplicity and rudeness of its artifacts are not the most distinguishing features of the Palæolithic Age. As we shall see presently, the relics of that age are most frequently met with in positions that plainly argue for them a much greater antiquity than can be assigned to the oldest relics of Neolithic times. Not only so, but Palæolithic man was the congener of many great mammals, that became either locally or wholly extinct before the appearance of his Neolithic successor in Europe. The animals with which the latter was contemporaneous belong, for the most part, to species still living in our Continent—the forms, in short, are familiar, although a few are now locally extinct, as

urus, wild-boar, wolf, and beaver, in Britain, all of which have vanished within historic times.[1]

I have referred to the stone tools used by Palæolithic man. It is remarkable that nearly all those implements are fashioned of flint and chert, and chiefly of the former; but he employed also granite, hard sandstone, grit, etc., as hammers or pounders, probably for mashing roots, breaking and crushing bones, and other purposes. Many artifacts, however, were formed of bone and horn. Among these are harpoon-heads, barbed on one or both sides, awls, pins, and needles, with well-formed eyes. More remarkable than these are the engraved and sculptured fragments of bone, horn, ivory, and stone, which some of the Palæolithic folk have left behind them. The engravings have been etched with a sharp-pointed implement, and are often wonderfully clever, and even artistic representations of the creatures they portray. Amongst many others we find characteristic representations of cave-bear, reindeer, mammoth, or woolly elephant, great Irish deer, ibex, bison, horse, etc., and occasionally even man. Besides etchings or gravings we meet now and again with carvings on the handles of daggers and other implements, such as representations of reindeer and mammoth. More notable still are ingenious statuettes in ivory of men and women, sometimes artistic, often crude. Again, the walls of certain

[1] The foregoing paragraphs, much abridged and otherwise modified, are taken from *Prehistoric Europe*, Chapter II.

PALÆOLITHIC IMPLEMENTS.



Types of the *Coup de poing* or Hand-axe.

Chellean (1, 2) 1*b* shows sinuous cutting edge of 1*a*.
Acheulian (3-5) 4, 5, preserve at the base portions of the original surface of the nodules.
All the figures on the plate are $\frac{1}{3}$ of the actual size.

From *Musée Préhistorique* by MM. G. and A. de Mortillet.

[*To face page* 40.

caves (occupied towards the close of Palæolithic times) are decorated with numerous engraved drawings, and even coloured representations of bison, horse, and other animals.

It is needless to say that the various implements and works of art thus briefly mentioned must belong to very different stages of the Palæolithic period. By comparing and contrasting the artifacts encountered in a large number of caves, archæologists were struck by the fact that the implements and ornaments occurring in one set of caves were indicative of a higher, or, as it might be, of a lower grade of culture than the artifacts characteristic of another series. It was inferred, therefore, that the caves in which the ruder implements were found had probably been occupied earlier than those from which the better finished implements had been obtained. Now and again, in fact, distinct stages of culture were observed in one and the same cave—the lower relic-beds showing simpler and ruder implements, while the upper deposits were charged with artifacts of a more advanced type.

Of late years evidence of this kind has greatly increased, and the general conclusions of archæologists have been thereby strongly supported. But however satisfactory and suggestive the evidence of cavern-deposits may be, it is, nevertheless, imperfect or deficient. Each cave, no doubt, contains the record of some portion of Pleistocene times, but no individual cave furnishes a complete consecutive

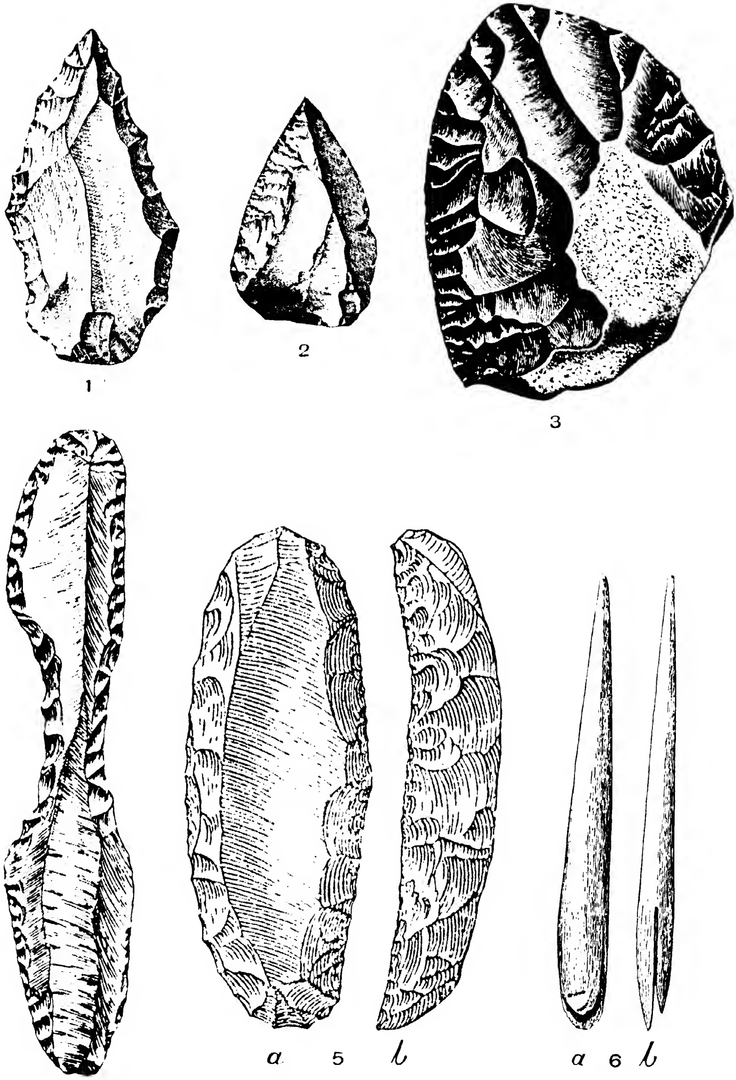
history. Fortunately, however, the evidence of the caves is supplemented and confirmed by that of ancient fluviatile and other accumulations, so that the succession or classification of culture-stages, which we owe chiefly to the genius of G. de Mortillet and other French archæologists, is now well established. As I shall have frequent occasion to refer to these culture-stages, I may name them now, but it will not be possible to give any particular account of their distinguishing characters. To do so would take up more time than I can spare, for the geological tale I have to tell is at once long and somewhat complicated, and it is the eventful history of the Pleistocene and its relation to the antiquity of our race with which I am chiefly concerned.

The archæological stages are as follows, beginning with the oldest:—

1.	Chellean	Older Palæolithic.
2.	Acheulian	
3.	Mousterian	
4.	Aurignacian	Younger Palæolithic.
5.	Solutréan	
6.	Magdalenian	
7.	Azilian	(Transition Stage.)
8.	Neolithic.	
9.	Bronze Age.	
10.	Iron Age.	

The CHELLEAN stage is so named from Chelles, a town east of Paris, where the Pleistocene river-drifts

PALÆOLITHIC IMPLEMENTS.



Mousterian: 1, 2/3; 2, 1/3; 3, 2/3. After MM. de Mortillet.
Aurignacian: 4, 2/3; 5 *a b*, 1/1; 6 *a b*, 1/2. After MM. Breuil and Bouyssonie.

[*To face page* 42.

rest directly on deposits of Tertiary age. The implement most characteristic of this stage is a large pointed artifact—the *coup de poing* (Plate XV, 1, 2) of French writers—which was not hafted, but appears to have been held in the hand, and is therefore sometimes called a "hand-axe" by English archæologists. The Chellean artifacts are associated with remains of the southern mammals. Some archæologists recognise two earlier stages than the Chellean, namely, the "Mesvinian" and the "Strepyan." The former of these is represented by simple flakes of flint, evidently man's handiwork, and is further characterised by the absence of the *coup de poing* or hand-axe. The "Strepyan," on the other hand, is marked by the presence not only of simple flakes but of primitive forms of the Chellean *coup de poing*. By other archæologists the Mesvinian and the Strepyan are not ranked as independent stages, but included in the Chellean, as "early Chellean."

The ACHEULIAN—named from St Acheul in the valley of the Somme—is represented by artifacts of the same type as those of the Chellean, but thinner and lighter, more shapely, and altogether better finished (Plate XV, 3-5). The fauna associated with the Acheulian artifacts includes both southern and northern forms, as the straight-tusked elephant (*Elephas antiquus*), and the mammoth or woolly elephant (*E. primigenius*).

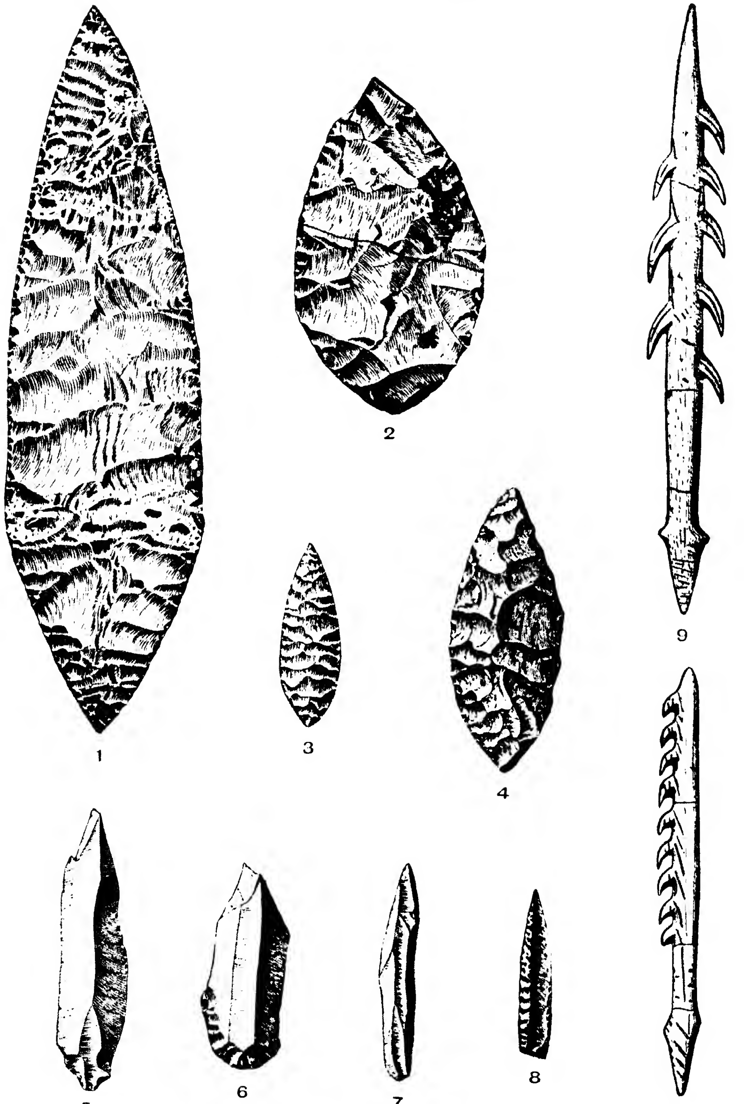
The MOUSTERIAN takes its name from the caves of Le Moustier in the valley of the Vézère. The im-

plements of this stage show a greater variety of form and are usually more finally chipped than those of the preceding stages. The *coup de poing* or hand-axe still occurs, but is rare, and would seem to have gone out of use in early Mousterian times. The fauna of this period was represented by mammoth, woolly rhinoceros, musk-ox, reindeer, lemmings, and other northern forms, together with brown bear, lion, hyæna, and leopard. In some cases, however, Mousterian artifacts are associated with remains of the southern mammalia. It may be added that while Chellean and Acheulian relics rarely occur in caves, Mousterian implements are most frequently met with in caves and rock-shelters—the men of that stage having been true troglodytes (Plate XVI, 1-3).

The AURIGNACIAN (so-called from the grotto of Aurignac, Haute Garonne) is represented by stone implements of many varied forms, and by artifacts of bone, horn, and ivory. To the same stage belong numerous works of art, such as figurines of women carved in ivory, besides etchings or engravings of various animals, and now and again the walls of caves occupied by Aurignacian man show painted designs. Among the mammalian remains of this stage are mammoth, woolly rhinoceros, bison, Irish deer, reindeer (not common), cave-bear, hyæna, etc. (Plate XVI, 4-6).

The SOLUTRÉAN (from Solutré, Saône-et-Loire) is characterised by beautifully shaped and finely finished flint implements, such as the so-called "laurel-leaf"

PALÆOLITHIC IMPLEMENTS.



Solutréan : 1, 2, 3, all $\frac{1}{3}$; 4, $\frac{2}{3}$.
Magdalenian : 5, 6, 7, 8, 9, 10, all $\frac{1}{2}$.

All figures from MM. de Mortillet's *Musée Préhistorique*.

[*To face page* 44.

and "willow-leaf" lance heads (Plate XVII, 1-4). Artifacts of bone and horn (sometimes engraved) and sculptures in stone are met with. Remains of horse and reindeer, but more especially those of the horse, are abundant. At the station of Solutré so numerous were the latter that it was believed they must represent about 100,000 individuals. Other animal remains are those of mammoth, urus, hyæna, wolf, cave-bear, etc.

The MAGDALENIAN (named from the rock-shelter of La Madeleine in the valley of the Vézère) is notable for the great variety of its artifacts of bone, horn, and ivory (Plate XVII, 5-10). Stone implements were still employed, but they exhibit on the whole inferior workmanship to those of the preceding stage. But the artistic efforts of Magdalenian man far surpassed those of his predecessors of Aurignacian and Solutréan times. His engravings and sculptures, his drawings and monochrome and polychrome paintings evince a skill and power which are simply astonishing. The walls and sometimes even the roof of his caves are decorated with frescoes representing chiefly the animals he hunted—bisons, horses, deer, etc. He has also left behind him characteristic engravings of the more notable carnivores and pachyderms of the time—cave-lion, cave-bear, mammoth, and woolly rhinoceros.

The AZILIAN stage I shall refer to more particularly in the sequel. Its chief interest arises from the fact that it helps to bridge over the gap which in many

places separates the Palæolithic from the Neolithic age. But to the consideration of this matter I shall return in a subsequent lecture.

It must not be supposed that the several archæological stages represent well-defined periods of time, or that they were all of equal duration. Neither do they necessarily represent a succession of different races. The human remains which now and again have been met with show, indeed, that one particular stage, the Mousterian, was characterised throughout by the presence of at least one special type of man. Several races, however, seem to have lived in Europe during subsequent Palæolithic times, but whether these represent just so many different folk-waves coming into our Continent, or whether one race may not in some cases have been evolved from another, we do not know. The oldest human skulls hitherto discovered are of Mousterian age—the earliest find of a tolerably complete skeleton having been made in 1857 in the Neandertal, not far from Düsseldorf. It was at first doubted whether these remains were really representative of a race. The skull had a certain primitive aspect, but it was thought that its simian characters might simply indicate an abnormal condition. So many discoveries of the same type, however, have since been made in different parts of Europe, that anthropologists are now quite assured that throughout Mousterian times there lived in our Continent a race characterised by a low retreating forehead, enormous brow ridges, large

round eye-orbits, massive jaws, and feebly developed chin. The heavy limb bones are curved, and the whole structure of the skeleton indicates a strong muscular man, some 5 feet 3 inches in height. Up till recently no skeletal remains of earlier date than these were known. A few years ago, however, an exceptionally massive lower jaw, with pronounced simian characters but a decidedly human set of teeth, was obtained from deposits near Heidelberg, which may date back to the Chellean or even to an earlier stage. Again, only the other day a fragmentary skull of very primitive type was discovered at Piltdown in Sussex, which may possibly be as old as or even older than the Heidelberg specimen. It is probable, therefore, that the Neandertal or Mousterian race was not the earliest to appear in Europe.

Of Aurignacian man several skeletons have been preserved. He was of a more advanced type than his Mousterian predecessor—the skull being highly developed, with a large and lofty forehead, less protruding jaws, and a rudimentary chin. He was also taller (5 feet 10 inches), the limbs being, in striking contrast with those of the earlier race, slender as in modern man. Another race of Aurignacian age is represented by two skeletons found in a cave near Mentone, which are described as being somewhat negroid in character.

Magdalenian man appears to have been of small stature (5 feet 2 inches to 5 feet 4 inches). His

skull, however, is shapely and lofty, the eye-orbits only moderately prominent, the chin well-formed, and the face in profile orthognathic. (See NOTE 4.)

After this rapid glance at the general results arrived at by archæologists and anthropologists, we may next consider the nature of the evidence furnished by caves and rock-shelters as to the antiquity of man. For our present purpose it is hardly necessary to enter into any detail as to the formation of caves. Most of the large and important caves occur in limestone, those excavated in other kinds of rock being usually of inconsiderable size. Nearly all owe their origin to the chemical and mechanical action of rain and running water, while a few have been formed in other ways. The caves of most interest to the student of Palæolithic times are of two kinds —some having been formed at the surface and in the light of day, while others have been hollowed out below ground by the action of water.

Those of the former class are commonly of smaller size than the others, and are typically represented by the hollows that occur at the base of many inland cliffs, and by the sea-caves so commonly met with along existing coast-lines and in connection with old raised sea-beaches.

Usually the hollow at the base, or at any intermediate level between the base and top, of an inland cliff marks the outcrop of some relatively soft or readily disintegrated rock. Should such a soft rock happen to be washed by stream or river, a hollow

of considerable size may be scooped out. For the formation of such hollows, however, it is not necessary that the strata should consist of unequally yielding materials. Cliffs of homogeneous material are often undercut by streams, simply by mechanical erosion.

The mode of formation of sea-caves is familiar to all, and need not be considered; they and the more or less shallow rock-shelters that occur in the face and at the foot of inland cliffs and steep slopes, may of course be excavated in almost any kind of rock.

The second class of caves includes all the most extensive underground galleries, many of which ramify in various directions, winding tortuously about and often opening on either side into similar intricate grottos. All these cavities owe their origin to the action of underground water. The chemical composition of springs might well lead us to expect that the more soluble rocks of the earth's crust must often be honeycombed and excavated to a very considerable extent, for the amount of mineral matter brought to the surface in solution is enormous. It is not surprising, therefore, that now and again the ground subsides where soluble rocks occur. Such subsidences often take place in regions of calcareous strata — these rocks being usually tunnelled and undermined by water descending from the surface by fissures and other natural division-planes. Owing to its content of carbonic acid the water dissolves the rock, and thus widens the fissures through which it makes its way; and as these increase in capacity

and give passage to larger bodies of water, they tend to be still further enlarged by the filing action of the stones, grit, and sand swept along. Most of our great caves, therefore, are simply the deserted channels of subterranean streams and rivers.

Many such underground water-courses are well known, and the direction of some of them can be traced by swallow-holes, chasms, and sinks, which indicate where the roofs of the cavities have fallen in, or have been pierced by acidulated water. In certain regions nearly all the drainage is conducted underground. Rivers after flowing for a considerable distance at the surface suddenly disappear, to follow a hidden course for many miles, it may be, before they again emerge. Sometimes, indeed, they never reappear, but enter the sea by subterranean channels. As the streams work their way down through massive limestone, many modifications of the underground labyrinths are effected; new channels being gradually opened up, while old courses are abandoned. The latter then become more or less dry galleries, and owing to the gradual lowering of the surface by subaërial denudation, may eventually become accessible by one or even by several openings. As might have been expected, therefore, limestone-caves are of common occurrence in valleys, and frequently open on steep hill-slopes or in river-cliffs.

It may be well now to give some account of the deposits met with in caves. These are of several kinds, but I shall describe only those that are

common to most of the caves that contain relics of Palæolithic man. The deposits in question consist usually of gravel, sand, and silt, of reddish earth (known as "cave-earth"), of stalactites and stalagmites, and of fallen rock-fragments. (See Fig. 1, p. 53.)

(*a*) The gravel, sand, and silt are obviously water-formed, and in many cases have been introduced by adjacent streams or rivers when these flowed at a higher level. Not infrequently deposits of this kind are the oldest met with in a cave, and when such is the case they rest directly on the rocky floor. After the neighbouring stream or river had cut its bed to a lower level, the time came when it could no longer reach the cave, even during flood. The cave then remained dry, and might become the abode of man or of wild beasts.

(*b*) The cave-earth consists of the insoluble residue of limestone. In bare uplands and plateaus limestone usually presents a more or less corrugated surface—irregular ridges of naked rock running in various directions, with intervening hollows of equally irregular form. This characteristic configuration is mainly due to the chemical action of rain which removes the carbonate of lime in solution, leaving behind the insoluble residue of the rock—a kind of reddish earth, which thus tends to accumulate in superficial hollows. But during heavy rain or the melting of snow, much of that earth may be swept down through sinks and swallow-holes into underground cavities of all kinds; while loose stones and skeletal remains

lying at the surface of the ground have doubtless often been introduced in the same way.

(*c*) Stalactites and stalagmites are invariably present in limestone caves. Carbonated water oozing out on the roof is exposed to evaporation, and compelled to part with some of the calcareous matter held in solution, which adheres to the roof. When the gathering drops fall to the floor they are subject still further to evaporation, and give up the remainder of their calcareous content. This action carried on for a considerable time results in the formation of long pendants hanging from the roof like giant icicles, and of bosses and conical hummocks rising as it were from the floor to meet them. Not infrequently indeed stalactites and stalagmites do meet, and then have the appearance of fantastic pillars that seem as if they had been designed to support the roof. The stalagmites may consist of pure carbonate of lime, but are often stained throughout with red earth. Their rate of growth is very variable. A layer nearly a quarter of an inch is said to have accreted in one year in a cave at Ingleborough. That must be an exceptional case, however, for with such rapid accretion all limestone caves must long ago have been filled up. If the rate of accretion in any particular cave had never varied, we should have no difficulty in ascertaining the age of its stalagmites. The rate is no doubt determined by physical and climatic conditions, and as these have probably remained much the same since early historical times,

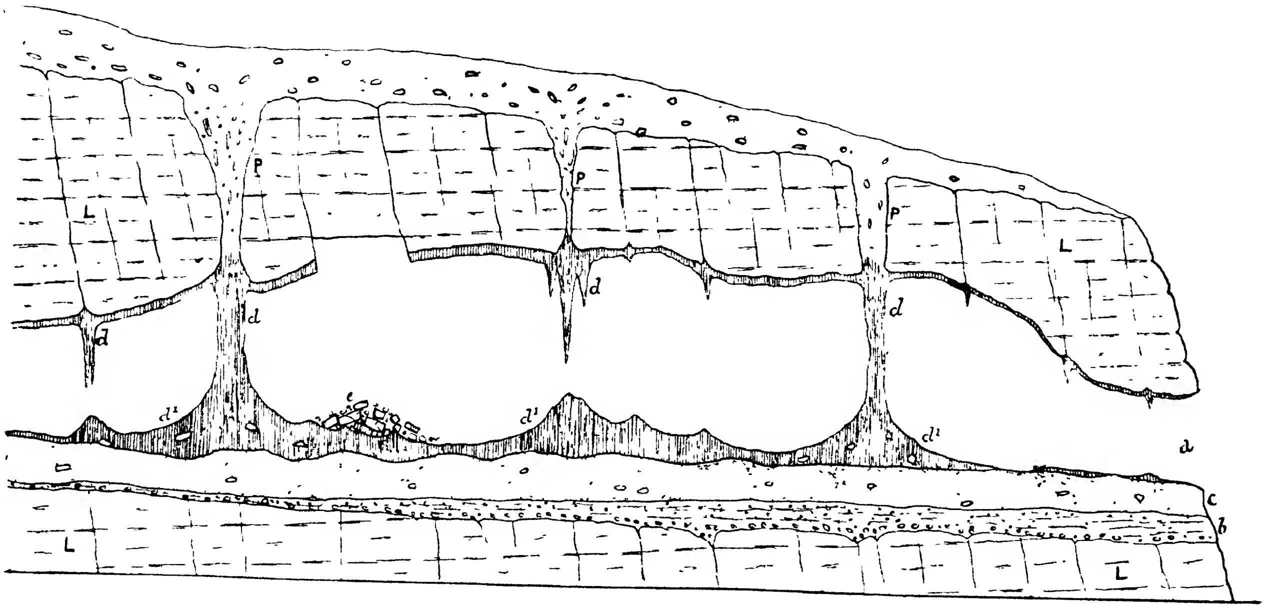


FIG. 1.—DIAGRAM OF A LIMESTONE CAVE.

LL, Limestone; PP, pipes filled with debris; *a*, entrance; *b*, river deposits; *c*, cave earth; *d*, stalactites; d^1, stalagmite; *e*, blocks fallen from roof.

estimates based on the present rate of growth might be fairly reliable for the past two or three thousand years. But to measure the rate of accumulation throughout the far distant Pleistocene period by that of the present would be an unreliable extrapolation.

During the exploration of the famous Kent's Cavern, near Torquay, a number of names and dates carved on a bed of stalagmite were detected. Some of these go back to the beginning of the seventeenth century, but although calcareous matter has been continually accreting on them ever since, it has been at so slow a rate that the inscriptions are still perfectly legible. On the surface of a large boss that rises above the general level of the floor of the cave, and thus marks a spot where the drip has been more continuous, and the growth, therefore, more rapid than elsewhere in the cave, there is this inscription—"Robert Hedges of Ireland, Feb. 20, 1688." Yet the film of stalagmite formed over it is not more than the twentieth of an inch in thickness; nor is there any direct evidence to show that accretion of this particular boss was more rapid in earlier times. The bed of which it forms a part is of very variable thickness, being hardly an inch in some places, while in others it swells out to as much as five feet. If, therefore, we took the rate at which the large boss has accreted during the past two centuries as a reliable standard of measurement, we should be compelled to infer that this layer of stalagmite began to form about

240,000 years ago. On the same computation still greater would be the age of an underlying bed of stalagmite, occurring in the same cave. The latter attains a thickness of twelve feet, and at the present rate of accretion must have required 576,000 years for its growth. These estimates, however, are unreliable, for they are based on the assumption that the conditions have remained unchanged throughout the whole period of accretion. But such we know has not been the case. Not only has the region been greatly modified by denudation, but several climatic revolutions have taken place since the formation of the stalagmites commenced. It might quite well be that stalagmitic growth was formerly much more rapid than is now the case. Nevertheless, even on the most extravagant assumption as to the former rate of accretion, we are forced to admit a period of many thousands of years for the formation of beds of stalagmite as thick as those I have mentioned.

(*d*) Large and small fragments of limestone, obviously fallen from the sides and roof, are of common occurrence in all cave-deposits. These seem to be present most abundantly in the chambers of galleries that open directly to the day, or which can be shown to have formerly had some such direct communication with the external atmosphere. The uppermost layer in which traces of prehistoric man and the Pleistocene mammals occur, is frequently sprinkled with numerous fallen masses, and sometimes with a more or less thick breccia or solidified

aggregate of fragments of limestone of all sizes, by which the entrance to a cave may be blocked up.

These fragments have been detached from the rock in various ways. Gradual widening of joints or fissures by the corrosive action of percolating water loosens large and small fragments from time to time. By this means rock-falls may take place at any moment, in any part of a cave, and under any conditions of climate. Not improbably the tremors and vibrations caused by earthquakes may occasionally shake down loosened blocks. But neither of these explanations accounts for the more abundant presence of blocks and debris in the vestibules of caves. Obviously those parts of a cave are most subject to the influence of the external atmosphere, and we shall probably not be far wrong in attributing the dislodgment of the blocks and debris in question to the action of frost, which during the prevalence of tundra climatic conditions must have been very effective. In the deeper recesses of the caves the cold would be less intense, and perhaps that is the reason why falls from the roof are less notable in these parts.

We must now study a few typical examples of caves from which relics of prehistoric man have been obtained. The caverns and rock-shelters ransacked by archæologists and geologists are numerous indeed. Our own islands, Belgium, France, Spain, Germany, Switzerland, Austria, and most of the Mediterranean coast-lands of southern Europe have furnished excellent examples. It is impossible, therefore, to do more

than select a few which may be considered as more or less representative. I shall consequently limit myself to a short description of such as have special interest from a geological point of view—those, namely, that afford the most direct testimony to the antiquity of man. We shall find that these caves not only yield clear evidence of those successive stages of culture which are of so much interest to archæologists, but are often eloquent of climatic and geographical changes.

KENT'S CAVERN.—The first example of a cave I take has already been mentioned in connection with the origin of stalagmites. Beginning with the lowest and therefore the oldest deposit met with on the floor of this notable cave, we have the following succession :—

1. *Breccia.*—An aggregate of subangular and rounded stones, in a red sandy matrix. This deposit, consisting as it does of water-worn stones, etc., foreign to the hill in which the cave occurs, proves that from time to time water coming from some adjacent higher ground invaded the cave. The presence in the breccia of remains of the bear and a few Chellean stone implements indicates that now and again the cave was occupied by bears, and occasionally visited by man.

2. *Crystalline Stalagmite.*—When this stratum began to form water had ceased to flow through the cave. The stalagmite bespeaks a prolonged period of gradual accretion, for it attains a maximum thick-

ness of twelve feet. There is evidence, however, to show that after a considerable mass had accumulated, it was undermined by torrential waters which had again invaded the cave. The stalagmite was thus to some extent broken up, and considerable portions of it and the underlying breccia were swept away. The cave, as before, continued at intervals to be occupied by bears.

3. *Cave-earth.*—This stratum was crowded with animal remains, both of extinct and living species, and it also yielded numerous relics of man's handiwork. Among the animals represented are sabre-toothed tiger, lion, wild-cat, hyæna, bear, mammoth, woolly rhinoceros, reindeer, Irish deer, red-deer, urus, bison, wolf, fox, badger, glutton, etc. Artifacts were abundant, including not only flint implements and cores or nuclei of flint, but bone-harpoons, awls, pins, and a bone needle. It is obvious that during the accumulation of the earth, which is often more or less strongly calcified, man frequently occupied the cave, while at other times (as the abundance of gnawed and broken bones sufficiently testifies) it became a hyæna's den.

4. *Black Band.*—Artifacts of stone, bone, and horn were very plentiful in this layer, which consisted mainly of charcoal. With these artifacts were associated burnt bones, and remains of ox, deer, horse, badger, bear, fox, woolly rhinoceros, hyæna, etc. The black band was met with only in one part of the cave, near the entrance, and represents the old

hearths round which Palæolithic man gathered to warm himself, and to do such primitive cooking as he required, which included the roasting of large bones for the sake of their juicy marrow.

5. *Granular Stalagmite.*—In this stratum, which varied from one inch to five feet in thickness, were found "stones of various kinds, shells of cockles and cuttle-fish, impressions of ferns, charcoal, bones and teeth of bears, mammoth, hyæna, woolly rhinoceros, horse, fox, and flakes and cores of flint." The granular stalagmite is discoloured with cave-earth, and tells much the same tale as the underlying black band.

6. *Black Mould.*—This deposit is of comparatively recent origin. It yielded articles of stone and bronze, and remains of a number of animals, all of which are still indigenous. A great hiatus therefore separates the black mould from all the underlying beds with their extinct and no longer indigenous species. The mould lay between and amongst large blocks of limestone, some of which rested upon it. I may add that similar fallen blocks, large and small, were encountered throughout all the cave-accumulations.

The chief results obtained from the examination of the deposits in Kent's Caverns may thus be shortly summarised :—

1. The co-existence of Palæolithic man and the Pleistocene fauna is demonstrated.

2. The prolonged duration of the period involved is proved not only by the great thickness attained by the stalagmites, but by the mechanical deposits

introduced by running water. It is evident that the whole configuration of the neighbourhood became eventually so modified by erosion, that the streams which at intervals had invaded the cave and its galleries were at last excluded.

3. The human relics obtained from the upper Palæolithic strata indicate a more advanced culture stage than those occurring in the breccia at the bottom. The latter, consisting of chert and flint only, are more massive, more rudely-formed, and less symmetrical than those met with in the cave-earth. They are probably of Chellean age, and have been formed by operating directly on nodules, of which portions of the original surface usually remain. The stone implements in the overlying beds on the other hand have been struck from blocks of flint and chipped into the desired shape—the cores from which the flakes had been obtained occurring now and again. We seem to have in the beds overlying the breccia representatives of at least two culture-stages—the Mousterian and the Magdalenian.

4. What kind of climate may have prevailed during the formation of the breccia there is no evidence to show. But we may safely conclude that the hunters and fishers, whose relics occur so abundantly in the cave-earth, the stalagmites, and the black band, lived under cold climatic conditions.

5. Lastly, as already indicated, a great break or hiatus separates the Palæolithic deposits from the abruptly succeeding black mould with its modern fauna.

Brixham Cave.—The next cave I shall refer to is that of Brixham, which occurs in the same part of England as Kent's Cavern, but on the opposite side of Torbay. The accumulations met with at Brixham are in descending order as follows:—

1. Stalagmitic floor—a few inches up to one foot in thickness.

2. Breccia of angular fragments of limestone which filled up the northern entrance to the cave but thinned off rapidly inwards.

3. Black bed—a peaty calcareous earth, one inch to one foot thick.

4. Cave-earth, two feet to four feet thick.—It contained numerous fragments of limestone—very small pieces up to blocks weighing one ton. Fragments of stalagmite or portions of an old "floor" also occurred.

5. Shingle, consisting of pebbles of several rocks, all, with the exception of limestone fragments, being foreign to the hill.

All the accumulations in this cavern, save the black bed, were more or less fossiliferous—the cave-earth being much the richest repository of bones. The animals represented are mammoth, woolly rhinoceros, horse, urus, red-deer, reindeer, roebuck, lion, hyæna, bears (several species), fox, badger, hare, rabbit, lemming, water-rat, shrew. A number of stone implements were scattered through the deposit.

The succession of changes indicated may be briefly stated.

The shingle at the bottom of the section has been introduced by water flowing over the country lying to the west of Brixham. Occasionally, however, the cave ceased to be thus invaded, and remained for longer or shorter periods dry. The relics of mammoth, horse, and ox, occurring in the shingle, may have been brought in during those dry intervals by lions and hyænas, for the bones have evidently been gnawed. At this period in the history of the cave the valley of Brixham and its tributaries must have been seventy to eighty feet less deep than at present.

After the cave had become largely choked with shingle, invasion by running water ceased, probably owing to the deepening of the channels outside. It was during that period of quiet that a first floor of stalagmite gradually accreted over the shingle.

A time came, however, when this stalagmite was broken up and the surface of the shingle-bed on which it rested was lowered. This change would seem to have been caused by a final irruption of water.

After that event the cave remained habitually dry —the only deposit laid down being red earth—the insoluble residue of the limestone itself. It is probable that to a considerable extent this material may have been introduced from the outside. The cave had now become the resort of hyænas and bears, and was occasionally visited by Palæolithic man. Eventually the drip from the roof succeeded in forming another stalagmitic floor, and the remains of carnivores along with those of their prey became sealed up.

Finally, the entrances to the cave were closed with an accumulation of limestone debris, and from that time it remained unused and untrodden until its discovery in 1858.

Here, then, we have evidence of the contemporaneity of man and the Pleistocene mammalia, and of the extreme antiquity of the period during which they were in joint occupation of southern England. At the time when the cave began to be visited by lions and hyænas and Palæolithic man, the valley of Brixham was considerably less deep than now. So long a time has elapsed since then that the small streams of the district have been able to excavate their beds in hard rock to a depth not far short of 100 feet. (See NOTE 5.)

In conclusion, it may be noted that the artifacts occurring in the caves of England belong chiefly to the Mousterian and Magdalenian stages—the former being best represented. Chellean implements are rarely met with, and the same is the case with Solutréan artifacts, while there would seem to be no indubitable trace of the Aurignacian stage of culture.

LECTURE III

THE TESTIMONY OF THE CAVES—*continued*

Continental Examples. Belgian Caves contain Relics chiefly of Mousterian and Magdalenian Culture-stages. French Caves yield Relics of all the Archæological Stages from Chellean to Neolithic, Bronze, and Iron. Examples: Caves of Le Moustier, La Chapelle-aux-Saints, La Ferassie, Grimaldi (Italy). Caves of Middle Europe: Caves of Sirgenstein and Ofnet representing all Culture-stages from Mousterian to Neolithic and Later Times. Rock-shelter of Krapina (Croatia). Rock-shelter of Schweizersbild (Switzerland).

In this lecture I continue my description of certain caves which appear to be somewhat representative; at all events they serve to illustrate the essential features of the geological evidence furnished by cave-accumulations in general.

The caves of Belgium, France, Italy, Germany, and other countries in Europe have yielded, one may say, very much the same kind of evidence as that supplied by the cavern-deposits of England. In certain of the river-valleys of Belgium, particularly in those of some of the tributaries of the Meuse, a number of fine caves and rock-shelters occur. They appear in rocky escarpments at different levels above the streams, from a few yards up to 200 feet, one of the best known being that of Spy, in which were

E

discovered two skeletons of Mousterian man. The floor-deposits in most of these caves consist usually of alternations of fluviatile sediments and cave-earth, with layers of stalagmite. To these accumulations the relics and remains of Palæolithic man and the Pleistocene mammalia are restricted. Above the ossiferous deposits comes a mass of yellow clay and angular fragments of limestone. Relics and remains of Neolithic man appear at and near the surface of this yellow clay, but they never occur underneath it. The stony yellow clay thus takes its place in the series between the deposits of the Old Stone period and those which mark the later or New Stone period. It is obvious that here, as in many other caves of north-west Europe, a break or hiatus separates the Neolithic from the Palæolithic age.

I need not enumerate the mammals, remains of which occur in the Belgian caves — they agree generally with the mammalian fauna of the Devonshire caves. It may be pointed out, however, that the lower and upper strata are distinguished by a certain notable feature. The lower beds are characterised by the great abundance of remains of the mammoth, while in the upper beds those of reindeer are much the most numerous, extinct forms being present in greatly reduced numbers. Belgian geologists, therefore, have recognised two stages in the Palæolithic period—an early or Mammoth period, and a later or Reindeer period; which correspond to the Mousterian and Magdalenian stages.

It may be added that during the earlier stage many of these Belgian caves were liable to be invaded by the rivers in flood-time. Long before the close of the Reindeer period, however, the valleys had been so deepened by erosion, that the caves in question could no longer be reached by the flooded streams. The Trou de l'Érable, for instance, which occurs at a height of some 200 feet above the river Molignée, was liable during the Mammoth period to be flooded, but before the end of the Reindeer period this was rendered impossible—the river having in the interval eroded its valley to a depth of over 170 feet.

Interesting and important as the researches in England and Belgium undoubtedly are, it must be admitted that the caves of France, which are probably more numerous than those of any other country in Europe, have yielded the most prolific and important results. Cave-exploration carried on through a long series of years by many devoted experts across the Channel has indeed given rise to a most voluminous literature, which it would be impossible to review in a short course of lectures like the present. And if to the work of French archæologists and geologists we add that of similar experts in other countries of Europe, it is obvious that all I can do is to select for description one or two caves as representative examples.

From the caves of Dordogne and Périgord, and those occurring in or near the Pyrenees, have been

obtained an abundant archæological harvest. It is by the careful study of all this material, as we have seen, that French archæologists have been able to construct a succession of culture-stages, which is found to harmonise in every essential with the results of cave-exploration in other lands. The establishment of such sequences is of special importance to the geologist, for the invaluable aid they afford in his attempts to unravel the complicated history of Pleistocene times. In the following brief sketch of the evidence obtained by French archæologists, therefore, our attention must be largely restricted to the order of succession of the cave-deposits, and to the proofs they yield of climatic changes. The abundant details gathered as to the life and doings of the ancient inhabitants of France are doubtless of surpassing interest. Into these, however, I cannot enter, but must keep as closely as I can to my special line of inquiry, namely, to the history of the Pleistocene period, and the evidences of the antiquity of man.

Not the least notable of the French caves are those of Le Moustier—a little plateau of horizontally-bedded limestone and shale that overlooks the river Vézère in Périgord. Here Mousterian man appears to have found a home for a prolonged period, and has left behind him very numerous and interesting relics. His chief occupations were hunting and fishing, and from the abundance of the remains of horse, wild cattle, and reindeer, we may infer that these animals

were his mainstay, supplying him at once with food and raiment. But he hunted also many others, especially musk-ox, ibex, chamois, and red deer, and now and again mammoth and woolly rhinoceros; while occasionally bears, lion, hyæna, glutton, arctic fox, and other carnivores were overcome. In the caves and rock-shelters of Le Moustier, we find the usual evidence of old hearths and of the manufacture of stone implements—flakes and nuclei or cores of flint being richly represented. The "lower grotto" of Le Moustier is particularly notable for the discovery there in 1907 of a human skeleton, that of a youth of sixteen years, which had obviously been covered up in Palæolithic times. This is one of several similar discoveries recorded from the caves of France. In the cave of La Chapelle-aux-Saints in the Department of Corrèze, for instance, the skeleton of a man about fifty years of age was revealed, after the removal of a considerable thickness of overlying undisturbed clay and cave-earth. These deposits were crowded with human relics of the same character as those met with in the grottos of Le Moustier. The body had obviously been buried in a grave, and not merely covered over with debris. Again, in the Cave of La Ferassie, Dordogne, yet another human skeleton has been unearthed. This discovery is particularly interesting, inasmuch as there is evidence in the cave-deposits of a succession of culture-stages. At the very bottom occurred a bed of red sand, above which came a layer containing Acheulian implements, and

overlying that a stratum characterised by the presence of Mousterian artifacts. It was at the bottom of this upper stratum that the skeleton lay. The succeeding layers contained artifacts differing from those of Mousterian type, and belonging to the Aurignacian stage of culture. In like manner the so-called Trilobite Cave, near Arcy-sur-Cure, has yielded a succession of culture-stages, including Mousterian, Aurignacian, Solutréan, Magdalenian, and Neolithic. (See Fig. 2.)

At Grimaldi, on the border of Italy, near Mentone, occur a number of caves, obviously excavated by the sea at a time when the land stood sixty-five feet lower than at present. The exploration of these caves by MM. E. Rivière, M. Boule, E. Cartailhac and Abbé de Villeneuve has been fruitful in results. In one, known as the Grotte des Enfants, we have clear evidence of changing climatic conditions. On the rocky floor of this cave a hearth was exposed, and Palæolithic man would appear to have been in occupation not long after the sea had retreated. The animal bones found at this level were those of the broad-nosed rhinoceros, lion, and ibex. The old Mousterian hunters having vacated the cave for a time, it was next taken possession of by hyænas, who turned up the ashes of the hearth and gnawed the bones left by the hunters. The presence of hyæna coprolites is additional evidence of the presence of that animal; Palæolithic man, however, by and by returned, probably after no long interval, for layers of ashes or hearths appear

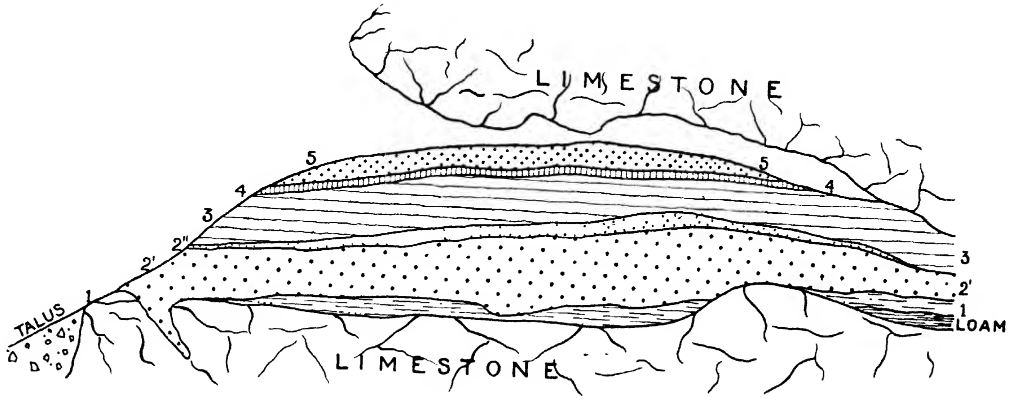


FIG. 2.—TRILOBITE CAVE. (After Abbé Parat).

1, Mousterian, 2', 2", Aurignacian; 3, Solutréan; 4, Magdalenian; 5, Neolithic.

immediately above the deposit in which the hyæna coprolites occur. Eventually he abandoned the cave for a protracted time, during which a thickness of three and a half feet of weathered rock-material slowly accumulated upon its floor. Resting upon this bed of barren rock-material or red clay is a well-marked hearth, showing that the cave again became the abode of man, who had now advanced to the Aurignacian culture-stage. On top of this layer of ashes and charcoal two skeletons were found—those of an old woman and a youth. The bodies had obviously been interred with care, for large stones had been so adjusted as to protect them. After this burial the cave was long deserted —a thickness of three feet of cave-earth having slowly accumulated before man reoccupied the place. His tenancy, however, was once more interrupted by a burial—that of a full-grown man, the body having been protected in the same manner as in the case of the old woman and youth.

The deposits overlying this level are of considerable thickness and consist principally of cave-earth, with a number of old hearths or layers of ashes occurring at irregular intervals. Thus it would seem that the cave was alternately occupied and abandoned by man through a lengthened period. The hearths indicate more or less continuous residence, but from the occurrence of artifacts throughout the beds of cave-earth it may be inferred that man often visited the place. Continuous residence was not without

its dangers, as is shown by the extensive rock-falls from the roof that have taken place. Near the top of the cave-deposits a great hearth or thick layer of ashes was met with, in connection with which two interments occurred—one that of an old woman, and the other that of two young children.

It is notable that many personal ornaments were found in all the graves—relics of armlets, necklaces, and decorations for head and breast. From the children's grave thousands of perforated shells were obtained, suggesting that the bodies had probably been clad in highly decorated garments.

An adjoining cave (Grotte du Cavillon) has yielded a succession of deposits, similar to those of the Grotte des Enfants. Towards the bottom of the series several old hearths occurred, with bones of broad-nosed rhinoceros, cave-bear, and elephant (*E. antiquus?*). Higher up the relics and remains agreed with those occupying the same position in the Grotte des Enfants—the artifacts of stone, bone, and horn being similar, and the animal remains representing cave-bear, brown bear, lion, hyæna, marmot, woolly rhinoceros, wild horse, urus, elk, red deer, wapiti, etc. The skeleton of a man was disinterred from these upper deposits. Round the skull lay many perforated shells, and a number of teeth of the red deer similarly pierced. Several interments of a like kind have been discovered in other caves at Grimaldi—all apparently belonging to the same Aurignacian stage of the Palæolithic period,

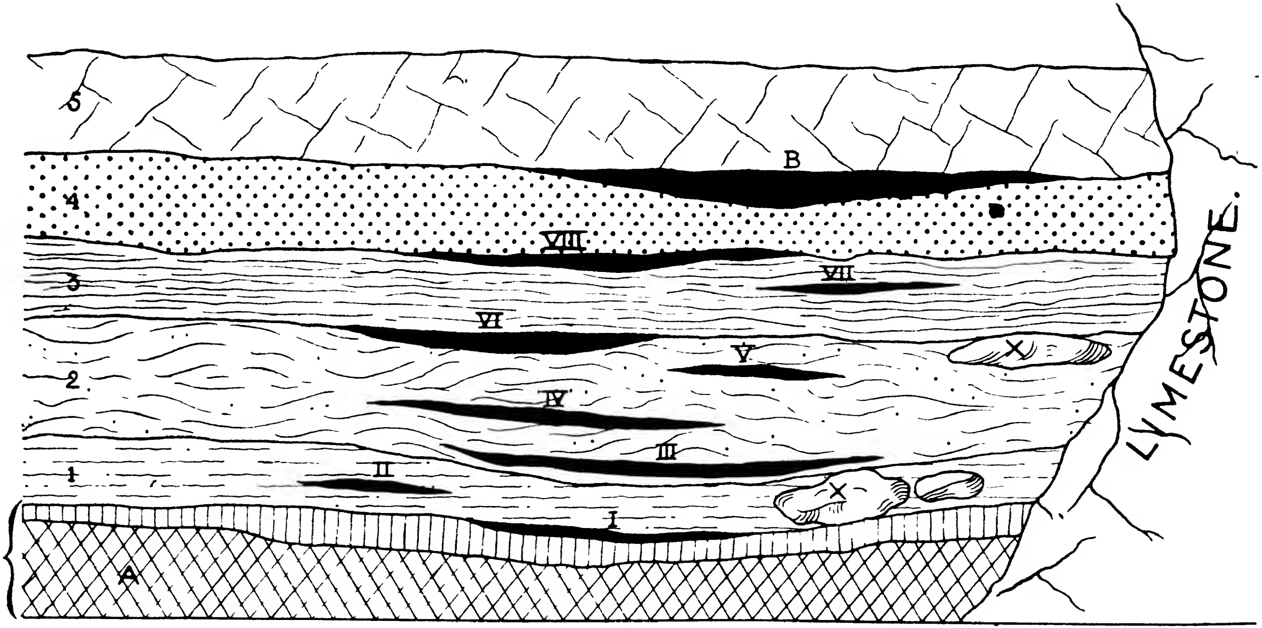


Fig. 3.—Succession of Deposits in Cave of Sirgenstein. (After Dr R. R. Schmidt.)

A, Tertiary; 1, Mousterian; 2, Aurignacian; 3, Solutréan; 4, Magdalenian; 5, Bronze and later ages; B, relic-bed (Bronze Age); I-VIII, Palæolithic hearths; X, X, Limestone blocks.

for the artifacts and the mammalian remains are the same throughout.

The Grotte du Prince, the last of the Mentone caves I shall refer to, affords even clearer evidence of changing climatic conditions than the Grotte des Enfants. The deepest stratum in this cave was of marine origin, charged with shells of still living Mediterranean species. Upon it rested an old hearth, with bones and teeth of elephant (*E. antiquus*), broad-nosed rhinoceros, wild horse, red deer, wild ox, brown bear, and hyæna. Higher up similar hearths or layers of ashes contained the bones of hippopotamus, horse (*Equus stenonis*), ibex, cave-bear, hyæna, panther, etc. The artifacts associated with this southern fauna were typical Mousterian. The deposits containing these remains were buried under great blocks of rock, a fall from the roof, which covered nearly the whole floor of the cave. The next folk to occupy the cave were accompanied by quite a different fauna—the mammalian remains representing horse, stag, roe, ibex (very abundant), wild cattle (not common), wolf, brown bear, cave-bear, panther, lynx, hyæna, and, most notable of all, reindeer, chamois, and marmot—a fauna obviously indicative of cold climatic conditions. The accompanying artifacts are of a rather indeterminate character, some suggesting the Aurignacian and others the Solutréan culture-stage, but none that can be recognised as definitely Magdalenian.

Within the past few years certain caves in

Germany have yielded very interesting and important evidence, which confirms and amplifies the results obtained from the study of the caves of France and Italy. Thus, according to Professor R. R. Schmidt, the cave of Sirgenstein—a prominent crag of limestone overlooking the Achtal in Würtemberg—contains a remarkably complete succession of Palæolithic culture-stages: Mousterian, Aurignacian, Solutréan, and Magdalenian occurring successively, one above another. (See Fig. 3, p. 75.) Again, in the Ofnet cave, near Nördlingen (Bavaria), the same explorer has found the following succession of stages:—Aurignacian, Solutréan, Magdalenian, Azilian, Neolithic, Bronze, and later periods. (See Fig. 4.)

In many other German caves traces of several culture-stages have been detected—implements of a very primitive type, when these are present, always occurring in deposits at or near the bottom, while Mousterian or later artifacts appear in overlying accumulations. In this respect, such caves have much the same tale to tell as not a few French, Belgian, and English caves, and do not therefore call for further notice.

There is one famous Austrian cave or rock-shelter, however—that of Krapina, in Croatia (see Fig. 5, p. 83)—of which some account must be given. It was explored by Dr Gorjanovic-Kramberger, who has published the results of his investigation in the *Proceedings of the Anthropological Society*

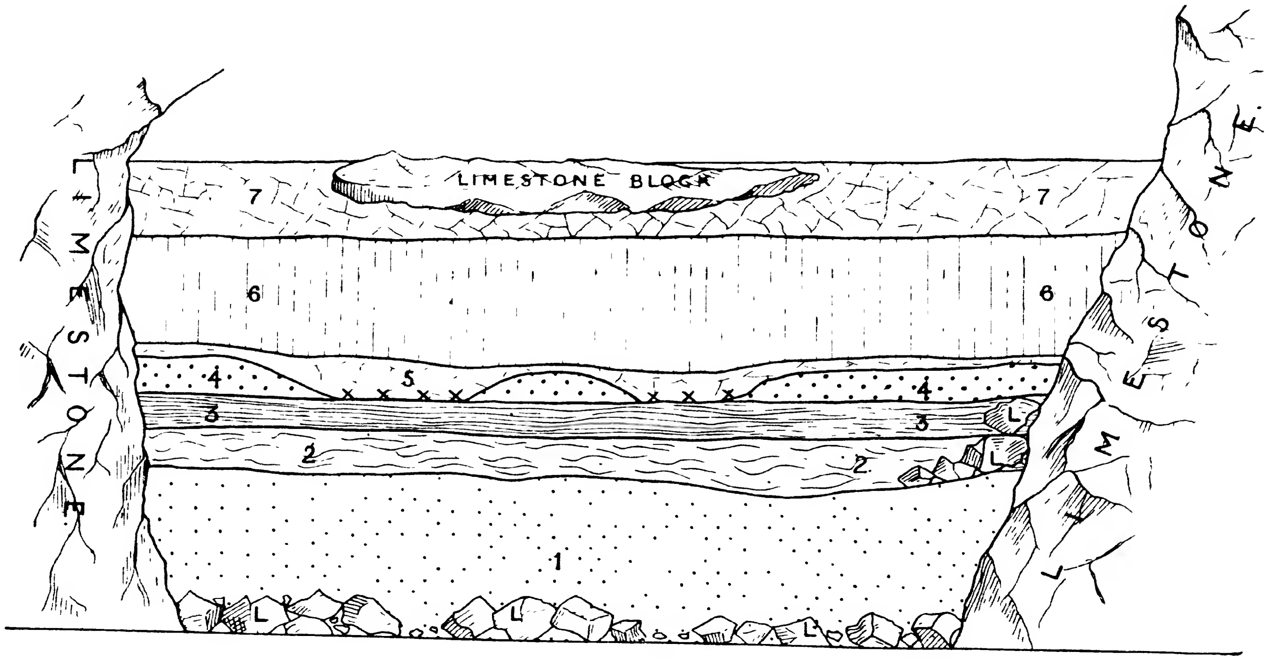


FIG. 4 —GREAT OFNET CAVE. (After R. R. Schmidt.)

1, Dolomitic sand, with limestone blocks and debris; 2, Aurignacian; 3, Solutrean; 4, Magdalenian; 5, Azilian-Tardenoisian (x, x, human skulls); 6, Neolithic; 7, Bronze and later periods.

of Vienna. The rock-shelter in question overlooks a small stream, to the excavating action of which it owes its origin. As the rocky floor of the shelter is now eighty feet above the present bed of the stream, it is obvious that a long time must have elapsed since the excavation was completed. Unlike many of the caves of which I have been speaking, that of Krapina has been hollowed out of sandstone, and its accumulations therefore differ essentially from those that appear in limestone caves. Its rocky floor is paved with water-worn gravel, sand, and silt, above which comes a thickness of twenty-five feet of sand, not of fluviatile origin, but obviously due to the gradual disintegration of the sandstone-rock under the influence of the weather. No stalagmite and no red earth are present. Palæolithic man seems to have utilised the shelter from a very early period. Even before the flooded stream had finally ceased to reach it, the old hunters occasionally visited the place, kindled their fires and cooked their food there, for old hearths, burnt bones, and stone artifacts occur near the bottom of the cave, intercalated between layers of fluviatile silt and mud. During the slow accumulation of the overlying sand under the influence of the atmosphere, man appears frequently to have occupied the shelter — no fewer than nine hearths occurring one above another at irregular intervals. Amongst the burnt bones those of cave-bear, broad-nosed rhinoceros, and bison are very numerous. By far the most notable, however, are those of

man himself. They indicate all ages, some being the remains of very young children, others those of full grown individuals. Nothing like a complete skeleton was found—only detached bones of every part of the body, confusedly commingled with those of animals, and all more or less broken and frequently burnt, the hollow bones having been split, doubtless for the sake of the marrow, and the crania are likewise shattered. Not unlikely, therefore, the men of Krapina may have been cannibals. From the two lowest hearths in the cave some five hundred fragmentary human bones were obtained, representing at least ten individuals. Most of the larger bones, those of man as well as wild beasts, were heaped against the walls of the shelter, as if they had been thrust aside to make room on the floor. Occasionally the shelter appears to have been abandoned by man, and when such was the case the great cave-bear took possession.

Of the numerous stone artifacts met with at Krapina, I need say no more than that they are of a somewhat primitive but indeterminate type, and have been assigned sometimes to the Mousterian, sometimes to the Chellean. But I would draw particular attention to the mammalian fauna. That is distinguished above all by the abundant presence of the broad-nosed rhinoceros, a species specially characteristic of the southern group, and by the total absence of the reindeer. None of the other animals whose remains occur at Krapina negative this evidence. Among

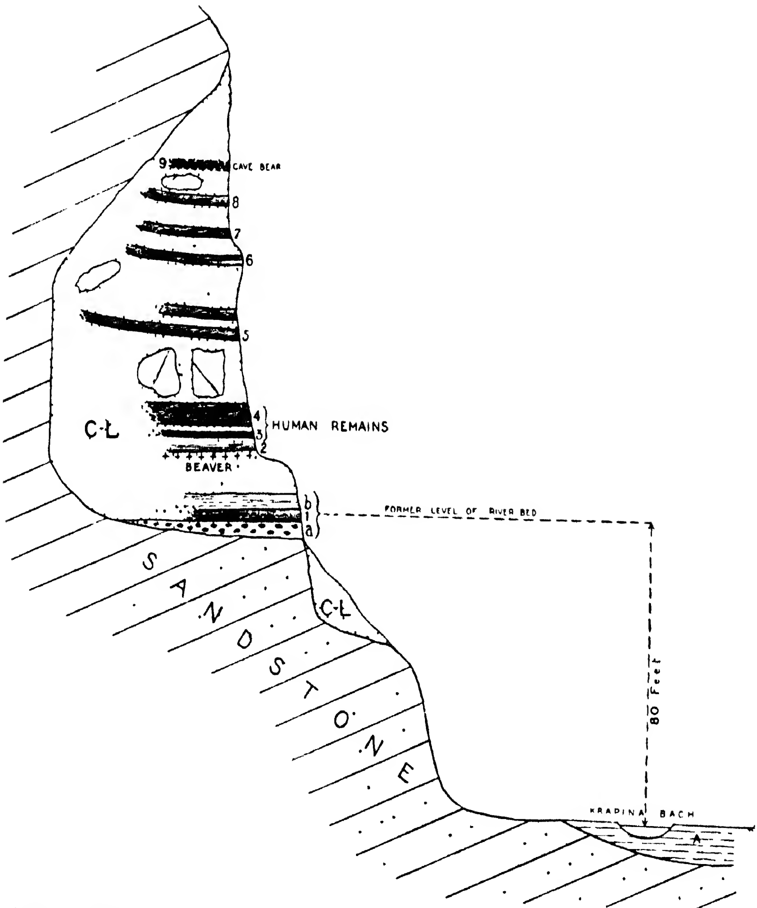


FIG. 5.—ROCK-SHELTER OF KRAPINA, CROATIA. (After Professor Kramberger.)

C-L Loamy sand; *a*, *b*, Fluviatile Alluvia, 1-9, relic-beds; A, Modern Alluvia.

these are wolf, brown bear, marten, otter, wild-cat, beaver, hamster, wild horse, wild boar, red deer, great Irish deer, and roe. The only animal present that might seem to indicate cool climatic conditions is the marmot, but its testimony is not sufficient to outweigh that of the others: and the entire absence of the more characteristic representatives of the tundra and steppe groups is, to say the least, highly suggestive.

The last example of a prehistoric dwelling-place I shall cite is that of the rock-shelter of Schweizersbild, near Schaffhausen, in Switzerland. The evidence yielded by this station is in many respects especially interesting and suggestive, and calls for a somewhat detailed description. I need hardly say that in my account I shall closely follow the admirable reports published by Dr Nüesch, to whom we are indebted for the discovery and exploration of the rock-shelter. The valley in which it occurs is a pleasant tree-girt meadow, in the midst of which rise some isolated stacks of limestone. From these rocks a wide view is obtained of all the adjacent valleys and heights, so that the place has always been a favourite resort of sportsmen. Here under the overhanging rocks they find shelter from wind and coarse weather, and welcome shade from the noontide sun. No doubt it was for similar reasons that the place commended itself to prehistoric man.

At the base of one of the stacks of limestone Dr Nüesch commenced his exploration, and after the

removal of a talus of soil and rock-rubbish various artifacts were discovered. Eventually the following succession of deposits was discovered :—

6. Humus-bed : 40 to 50 cm.

5. Grey Relic-bed : 40 cm.

4. Breccia-bed : average 80 cm. This bed was divided in two by a thin layer (about 10 cm.), termed the Upper Rodent-bed.

3. Yellow Relic-bed : 30 cm.

2. Lower Rodent-bed : 50 cm.

1. Gravel bed : dug to a depth of some yards.

The lowest bed (1) is an old river deposit which we need not consider. It contained no remains or relics of any kind.

The *Lower Rodent-bed* is a yellowish earth, containing many fragments of limestone, and the relics of a well-marked tundra fauna, such as banded lemming, arctic fox, mountain hare, and reindeer, along with northern field-vole, water-rat, glutton, weasel, ermine, wolf, fox, and bear. The only characteristic tundra forms that do not occur are the Obi or Siberian lemming and the musk-ox. The Obi lemming, however, has a somewhat more southern range at present than the banded lemming, and remains of the musk-ox, it may be noted, occur in the Kesslerloch, a cave in the neighbourhood, the contents of which belong to the same period as those of the rock-shelter of the Schweizersbild. With the tundra mammals of the rock-shelter various birds were associated, such as ptarmigan, grouse, pin-tail duck,

buntings, owls, falcons, etc.—an assemblage quite comparable with the bird-life of the Siberian tundras. The arctic fox and the banded lemming are especially characteristic of these far northern regions, and their presence at the Schweizersbild is therefore peculiarly significant. They range as far northwards as land extends, and are met with even in the islands of the frozen ocean. We cannot doubt, therefore, that while the lower portions of the Lower Rodent-bed were being slowly accumulated, an arctic climate reigned in north Switzerland.

As the Lower Rodent-bed and its contents are more narrowly scanned, it becomes obvious that the climate was beginning to change before the accumulation of the bed was completed. The tundra fauna was still in possession of the land when representatives of a sub-arctic steppe fauna began to put in an appearance. Amongst these new-comers were the little hamster (*Cricetus phæus*), common hamster, Siberian social vole, pika or tailless hare, wild horse, and woolly rhinoceros. Thus as we pass from the lower to the upper portion of the bed, a gradual change comes over the fauna—some species disappear, while new arrivals take their place. The extreme arctic conditions, evinced by the presence of a characteristic tundra fauna, were thus eventually superseded by a climate resembling that of the sub-arctic steppe-lands of Europe-Asia.

The most abundant remains in the Lower Rodent-bed were those of banded lemming—"the warmth-

hater"—as Middendorf has called it. The bones of this lemming and those of the birds are not broken, as are those of the larger animals. These last occur in small quantity, the most common being those of the alpine hare. Evidence of Magdalenian man's presence is furnished by flint implements, and by awls, chisels, harpoons, and needles fashioned out of bone and horn. Most of the bones appear as if they had been broken with stone-hammers, not a single marrow-bone having escaped such treatment. Throughout the entire thickness of the Lower Rodent-bed, however, only one old hearth with its ashes was encountered. From the fact that no burnt bones have been met with, and from the paucity of worked bones and antlers, contrasting so strongly with their abundance in the overlying beds, it is inferred that man was not a persistent occupant of the rock-shelter during the accumulation of the Lower Rodent-bed. This is further suggested by the occurrence, especially in the upper part of that bed, of abundant traces of various birds of prey, which appear to have been able to nest undisturbed on the rock and in its crevices. Probably at that stage the surrounding country had no large leafy trees or pine-forests, and supported merely dwarf bushes and scrub.

The next succeeding layer (*Yellow Relic-bed*) owes its yellowish red colour to an admixture of yellow loam, yellow-stained bones, and numerous stones which have been reddened by the action of fire.

The whole bed proved to be rich in relics of man. It yielded some 14,000 flint implements, and many worked bones and antlers, comprising needles, bodkins, and awls, chisels, harpoons, reindeer-whistles, etc. Bits of wood, worked and charred, and fragments of worked and unworked lignite were also obtained. Very notable also were the drawings and patterns etched on reindeer-antlers, on bones, and on tablets of limestone: while personal decoration was suggested by the occurrence of many shells, fossils, and teeth of the arctic fox and the glutton, which were perforated, as if they had been used for necklaces. From the presence throughout the relic-bed of nuclei or cores of flint, of abundant chips and splinters, of old hearths, ashes, and burnt bones, of stones discoloured and cracked by the action of fire, we may conclude that the reindeer hunters were constant occupants of the shelter during the accumulation of the Yellow Relic-bed. A large number of fossils, and various minerals, were found scattered through the bed. Some of these have been brought from no great distance, but others could not have been obtained in Switzerland. Either on account of their shape, their appearance, their colour, their size, or other character, they had somehow taken the fancy of the reindeer-hunters. No doubt some of them were used as ornaments, while others possibly may have been playthings for the children. Their presence, however, shows that the hunters occasionally wandered many miles away—to north, west, and

east. The occurrence of certain fossils, which in all probability have come from near Mainz and from the neighbourhood of Ulm, seems to show that the valleys of the Rhine and the Danube may have been the "trade-routes" of the period, the fossils being possibly used in barter. The stone-implements employed by the hunters were not fashioned of flint exclusively, but various other hard rocks were utilised, all of which could be obtained in the immediate neighbourhood. It is interesting to note, too, that slabs of schist and other readily-split rocks were found symmetrically disposed round the hearths, as if for seats. Anvils of granite were seen half-buried in chips, splinters, flakes, nuclei, and spoilt implements of flint.

Turning to the abundant animal remains, we find that these represent no fewer than forty-nine different species, thirty being mammals, fifteen birds, three amphibians, and one fish. Comparing this fauna with that of the Lower Rodent-bed, we see that the most characteristic tundra form, the banded lemming, is no longer represented. So, in like manner, no trace is found of lesser shrew, little hamster, bank-vole, alpine vole, Siberian social vole, northern field-vole, parti-coloured bat, rhinoceros, hawk-owl (*Surnia nisoria*), kestrel, etc. On the other hand, many new arrivals make their appearance. Amongst these are Pallas's cat or manul cat (*Felis manul*), spider musk-shrew, rufous suslik or sisel (*Spermophilus rufescens*), alpine ibex, Persian maral, dzeggetai or wild ass, pine

marten, beaver, squirrel, red deer, roe-deer, wild boar; various birds, including grouse, fieldfare, golden eagle, alpine lark, etc.; and species of toad, frog, and snake.

This is a steppe fauna, although not quite so characteristic and well marked as the tundra fauna of the Lower Rodent-bed. We note the absence of jerboa, but other not less characteristic steppe animals are present, such as the rufous suslik, the pika, and the true hamster. As constant visitors of the steppe-lands we note further Pallas's cat, wild horse, and dzeggetai, and some birds; while associated with these are several representatives of an arctic and alpine fauna, as the arctic fox, glutton, mountain hare, alpine ibex, and various birds. Amongst this company red deer, roe, wild boar, squirrel, pine marten, and beaver—all belonging to a forest fauna—seem out of place. It is to be noted, however, that they are represented by very few remains, and further that these are restricted to the uppermost part of the relic-bed, where the division between that bed and the overlying layer was not very sharply defined. Yet a forest fauna might well have been contemporaneous with a steppe fauna in Switzerland. It is quite possible that some of the lower heights of the neighbourhood may have been covered with a scrub of birch and pine, which would give shelter to deer, boars, martens, and squirrels, while bears and gluttons haunted some of the numerous open rock fissures, and owls and falcons nested in the cliffs.

The remains of reindeer are extremely abundant

in the Yellow Relic-bed—so abundant that Dr Nüesch estimates that the teeth, jawbones, and phalanges represent 500 individuals. But this estimate is probably too low. It would appear that the old hunters did not carry the entire carcase of a deer into the rock-shelter at the Schweizersbild. They cut it up where they had killed the animal, taking with them only the haunch and the hide, with the feet, and usually the head. Hence ribs, vertebræ, and bones of the pelvis are very seldom met with, while fragments of the skull are not plentiful. Both full-grown and young individuals are represented—the latter in astonishing numbers, it being computed that about one-third of the entire mass of bones are those of young deer. From this it has been inferred that the reindeer may have been domesticated, or else that the herds were so large that even with his imperfect weapons the hunter could have no difficulty in bringing down the victims he selected. In one of the drawings of reindeer found in the Yellow Relic-bed, it may be noted that double lines are shown passing along the side of the animal as if they were meant to represent a rein.

In fine, we have here a well-marked dwelling-place of the reindeer hunter of Magdalenian times. The various weapons and tools coming from the Lower Rodent-bed and the Yellow Relic-bed are all of the same type—that, namely, which is characteristically represented by the implements found at La Madeleine in the valley of the Vézère in southern France.

The next succeeding stratum is the *Breccia-bed* with the intercalated *Upper Rodent-bed.* The breccia consists of small angular fragments of limestone, either lying loosely together or cemented by calcareous matter. Where the bed was undisturbed it reached a maximum of 120 cm., and was similar in character throughout. The whole of the materials have no doubt been derived from the gradual weathering of the overhanging rock, and their accumulation implies a long period of time. Relics of man are not so abundant in this stratum as in the Yellow Relic-bed. Nevertheless, sporadic splintered bones and flint flakes and chips occurred all through the breccia, and here and there they were even numerous. About midway between the top and bottom of the breccia a layer of dark earth made its appearance, in which traces of man's handiwork and remains of rodents were conspicuous—this is the Upper Rodent-bed. During the formation of the breccia, the reindeer-hunters obviously visited the rock-shelter now and again, just as had been the case while the Lower Rodent-bed with its tundra fauna was being slowly accumulated. The assemblage of animal remains in the breccia shows very clearly that the climate was changing. The steppe conditions were passing away and forests were becoming dominant. Amongst the species met with in the Upper Rodent-bed are reindeer, hare, pika, squirrel-tailed dormouse, garden dormouse, squirrel, water-rat, various voles, shrews, mole, weasel, ermine, marten, etc. This is obviously a mixed fauna

—a few of the steppe animals being still represented, but the larger number of the species are forest forms. In short, we may look upon the breccia-bed as marking the transition from steppe to forest conditions. During the formation of the breccia the climate was gradually becoming milder — the forests continuing to increase at the expense, so to speak, of the older steppe flora. The presence of man is indicated not only by split bones and worked flints, but by the ashes of his fires. No objects fashioned of bone or horn, however, were met with.

The *Grey Relic-bed* is the stratum next in succession. This bed varies in character, but is noteworthy for the extraordinary quantity of ashes which it contains. Large blocks of limestone were found surrounding a central fireplace, while slabs of the same rock probably represented an old hearth. Besides these were many fragments of other rocks, together with fossils, shells, flint artifacts, bones, and antlers, human skeletons, red unglazed potsherds, and other relics of Neolithic man. Traces of at least twenty-two interments were discovered. These graves were sunk into the underlying Palæolithic beds, and naturally enough, therefore, some Palæolithic artifacts were here and there found in the Grey Relic-bed. But in places where no interments had taken place, the latter bed possessed quite a distinctive character, and was clearly recognisable as Neolithic. Many considerations lead to the belief that during the long Neolithic period the Schweizersbild was not occupied

as a dwelling-place, but was simply visited from time to time for burial purposes. It is also highly probable that the great accumulation of ashes in certain places indicates that here Neolithic man sometimes burnt his dead.

The fauna of the Grey Relic-bed includes brown bear, badger, marten, wolf, fox, mole, hare, beaver, squirrel, hamster, water-rat, urus, ox (*Bos taurus brachyceros*), goat, sheep, red deer, roe-deer, reindeer, wild boar, horse, and ptarmigan. Of these, badger, wild-cat, hare, urus, ox, goat, and sheep are new-comers, no trace of which is met with in the Yellow Relic-bed. Amongst the species present in Palæolithic times the following are now wanting: Pallas's cat, arctic fox, ermine, weasel, glutton, spider musk-shrew, field-vole, rufous suslik, pika, alpine hare, bison, ibex, dzeggetai, Persian maral, and all the birds with the exception of ptarmigan. The most abundant remains were those of the red deer, after which came those of roe-deer, horse, and ox. Neglecting the reindeer—the remains of which may have been derived from some of the older beds—it is obvious that the fauna of the Grey Relic-bed is a true forest fauna.

Among the Neolithic interments ten were of children, three of these new-born infants, while the others were respectively three months, two years, four years, and seven years old, when they died. Two of the infants had been buried with their mothers, and their graves contained no relics, while those of the

other children did, the relics consisting of shells and finely finished flint implements. The great care with which the graves have been constructed, and the presence of the ornaments and other valuable objects placed beside his dead little ones, evince Neolithic man's family affection. The new-born infants were laid each within the right arm of its mother, while with the left arm stretched across her breast the latter seemed to hold the little one fast. The examination of the skeletons of fourteen adults shows that during Neolithic times the Schweizersbild was frequented by two distinctly different races. One of these was of fair stature (1600 mm. and more), while the other was much smaller, a true pygmy race. Professor Kollmann, who has described the remains, is certain that the dwarf-like proportions of the latter have nothing in common with diseased conditions. This, from many points of view, is an interesting discovery. It is possible, as Dr Nüesch has suggested, that the widely-spread legend as to the former existence of little men, dwarfs, and gnomes, who were supposed to haunt caves and retired places in the mountains, may be a reminiscence of these Neolithic pygmies.

The highest-lying accumulation—the *Humus-bed*—is an agglomeration of breccia, earth, and rolled stones, through which were scattered various human relics, ancient and modern, such as glazed and unglazed potsherds, fragments of hand-made tiles, of modern bricks and clay-pipes, of glass of all kinds, coloured and

colourless, iron nails of old and recent kinds, buttons of metal, bone, and horn, ancient and modern metal rings, bronze needles with and without eyes, beads, etc. Along with these occurred many bones—the relics of hunters' repasts. Amongst the remains were those of domestic cat, beech marten, hare, rabbit, ox, sheep, elk, red deer, roe, domestic pig, horse, pigeon, and goose—a fauna like that of the present. The elk, it is believed, lived in the neighbourhood during the Middle Ages.

Dr Nüesch has made a rough estimate of the time required for the accumulation of the several deposits met with in this most interesting rock-shelter. Assuming that the Neolithic age closed some 4000 years ago, he infers that the Humus-bed has taken that time for its accumulation. The bed in question has an average thickness of 45 cm., and has accumulated, therefore, at the rate of 10 cm. in 1000 years. Taking this as the average rate of formation of all the other beds, he obtains the following results :—

Humus-bed = 4000 years.
Grey or Neolithic bed = 4000 years.
Breccia-bed = 8000 to 12,000 years.
Yellow Relic-bed = 3000 years.
Lower Rodent-bed = 5000 years.

The entire series of deposits (240 to 250 cm. in thickness) thus represent a period of 24,000 to 29,000 years. Too much reliance must not be placed on these estimates, and Dr Nüesch mentions several considerations which might reduce the period to

something like 20,000 years or less. But they show at least that many thousand years have elapsed since the first appearance of man at the Schweizersbild.

The Palæolithic remains, however, belong only to the later stage of the Old Stone period. In the rock-shelter of the Schweizersbild no trace of any earlier stage is visible—the story begins abruptly with the last chapter in the history of Palæolithic times. Although it thus deals with only a limited portion of that history, it has nevertheless demonstrated certain notable facts. In particular it has shown that tundra, steppe, and forest faunas have succeeded each other—a conclusion already arrived at from a study of Pleistocene deposits elsewhere in Europe. Further, it introduces us for the first time to a lost race of Neolithic pygmies. Lastly, we have in the Schweizersbild rock-shelter one of the most complete sections yet discovered, showing the relation of the Upper Palæolithic to the succeeding Neolithic and later stages. At the Schweizersbild, probably no long interval occurred between the departure of Palæolithic and the advent of Neolithic man. It is even quite possible that the latter arrived before the last of the reindeer-hunters had vanished from Switzerland. From evidence supplied by certain Pyrenean caves, a similar inference has been drawn. But, even if it should afterwards be ascertained beyond any doubt that Palæolithic and Neolithic man came into contact here and there, it would not follow that this was general throughout Europe. We now know that

Palæolithic man retreated from the low grounds of our Continent along with the gradually retiring sub-arctic steppe fauna, and that Neolithic man came with the succeeding forest fauna. It is not improbable, therefore, that Neolithic man may have been in full occupation of southern Europe, while Palæolithic man was still hunting the reindeer in France and central Europe; and it is even possible that the two races may have touched along the margins of their respective territories. The evidence of the Pleistocene deposits of northern and north-western Europe, however, would seem to show that long before Neolithic man entered those regions, Palæolithic man had taken his departure.

The rapid review I have now given of the evidence furnished by a few notable European caves, however imperfect it may be, is yet sufficient to establish certain conclusions. The facts convince us that prehistoric man was certainly contemporaneous with not a few extinct and no longer indigenous animals. They further demonstrate that his occupation of Europe was of prolonged duration: and that he certainly experienced several remarkable changes of climate. But the evidence of the caves, it must be admitted, is partial or incomplete—each seldom giving us more than two or three chapters of Palæolithic history, and the correlation of all these scattered and interrupted records necessarily entails a certain amount of conjecture. Nevertheless, the tentative views set forth years ago by archæologists have been

thoroughly justified. It cannot be doubted that during Pleistocene times there was a gradual progression of our race, from an age when only very simple and rudely fashioned stone implements were used, to a time when finely-formed artifacts of bone and horn came to be manufactured by folk possessed of notable artistic talents. There are certain links in the chain of evidence, however, which are still wanting. The evidence of the caves, as I have said, is incomplete. But as I hope to show in my next lecture, abundant traces of man's handiwork occur elsewhere than in caves, and these help to fill up the lacunæ, and so enable the archæologist to follow the career of our race more or less confidently through the whole course of Palæolithic times.

If the archæological evidence of the caves is not so full and complete as it might have been, the same is the case, and in larger degree, with the geological evidence. We meet with certain proofs of changing climatic conditions, as supplied by the alternate appearance and disappearance of more or less strongly contrasted mammalian faunas. But highly suggestive as that evidence may be, there is yet much more that we should like to know. Fortunately this additional knowledge has been obtained in no small measure from a study of those alluvial and superficial formations which form the subject of succeeding lectures. (See Note 6.)

LECTURE IV

THE TESTIMONY OF THE RIVER-DRIFTS

General Character of Pleistocene River-drifts. The Typical Succession of Deposits in the Somme Valley. Drifts of the Thames Valley. Evidence of Great Denudation and of Climatic Changes: Genial, Temperate, and Arctic Conditions. The "Trail" or "Contorted Drift," and its Significance. The Succession of Archæological Culture-stages confirmed by the Evidence of the River-drifts. The Loess: Tundras and Steppes of Middle Europe.

In my last lecture I discussed the general nature of the evidence yielded by cave-accumulations as to the antiquity of man. That evidence leaves us in no doubt that our Palæolithic predecessors lived under climatic conditions that must sometimes have differed very considerably from those of modern Europe. In certain caves we find human relics associated with a mammalian fauna clearly indicative of warm or genial conditions; while in other caves the animal remains are those of northern or even of arctic types. Now and again, indeed, representatives of southern, temperate, and northern faunas occur at different levels in one and the same cave. The changes of climate thus vouched for necessarily imply a very long lapse of time. And the same conclusion is

forced upon us when the nature and origin of the cave-accumulations themselves are considered—the red earths and stalagmites, namely, in and underneath which human relics occur. These formations, it is true, do not enable us to formulate any precise or definite estimate of the time required for their accumulation. But they at least assure us that the caves must have sheltered Palæolithic man for many thousands of years. Nor does their evidence stand alone; it is supported by that derived from a consideration of the amount of valley-erosion effected by adjacent streams and rivers since the caves first came into occupation.

However important the evidence of the caves may be, it is obviously fragmentary. No one cave has yielded a complete record of Palæolithic and later times. Nevertheless, by comparing the human relics from a large number of caves, archæologists have succeeded, as we have seen, in showing that these belong to different phases of culture and are suggestive of gradual progression. It has now been definitely established that during Pleistocene times the race advanced from a very primitive stage, when man used only the simplest and most rudely-fashioned flint-implements, to a stage when finely-formed artifacts of stone, bone, horn, and ivory came to be manufactured by a notably artistic folk.

We have next to learn that the evidence of the caves is supported and supplemented by that of certain other Pleistocene formations. Not only so,

but from a study of the latter we have acquired a clearer conception of the climatic and geographical conditions that obtained in Europe during its occupation by our savage predecessors. The formations I refer to are of very diverse origin. Amongst them are freshwater and marine deposits, and enormous sheets and heaps of glacial debris. With the history of all those varied formations, the question of the antiquity of man is intimately bound up. It is only of late years, however, that this has been recognised. For a long time archæologists and geologists were of opinion that our cave-accumulations and certain ancient river-gravels and loams which had likewise yielded human relics and remains, all belonged to a later date than the Pleistocene glacial accumulations. That such is not the case I shall subsequently endeavour to demonstrate, but for the present we may restrict our attention to those ancient alluvia in which Palæolithic relics occur along with the remains of extinct and exotic mammals.

The deposits in question are well developed in such valleys as those of the Thames and other streams in the south of England, and in many similar valleys in France and Belgium. As they have been long studied in France and England, the river-drifts of those countries are well known, and may be taken as more or less representative. The valleys occupied by them are obviously of fluviatile origin, and it is worthy of note that when the process of excavation had been completed, and the valleys had

attained their greatest depth, the land must have been somewhat more elevated than now. This is proved by the simple fact that the bottoms of the valleys lie at considerable depths below the present rivers. In the London district, for example, the floor of the old Pleistocene valley underlies the Thames at a depth of at least seventy feet, while that of the Seine in the neighbourhood of Paris is similarly depressed.

The river-drifts about to be described often cloak the valley-slopes more or less smoothly; not infrequently, however, they present the aspect of somewhat ill-defined platforms or terraces. Occasionally they appear as isolated patches or irregular interrupted sheets, especially at the higher levels; at lower levels they are usually more continuous. Although the deposits differ considerably in character, two more or less well-marked kinds may nevertheless be distinguished—namely, "*gravels* and *sands*," and "*loams* and *brick-earths*." The gravels and sands are clearly of fluviatile origin, for they consist of materials derived from the drainage-areas in which they occur, arranged in layers parallel to the inclination of the valley-bottom. Although the stones are usually rounded and water-worn, and the deposits distinctly stratified, such is not always the case. Occasionally the stones are rough and angular, and the confused aspect of the deposits suggests somewhat tumultuous action. Now and again, indeed, large erratic blocks occur, such as might have been

carried by river-ice, while the bedding may be much disturbed, as if from the grounding of ice-rafts.

The loams and brick-earths, while consisting mainly of fine-grained materials, occasionally show lines and layers of so-called "angular gravel"—that is, rough stones, unlike the smoothly rounded stones that form the bulk of the gravel and sand series. These loamy deposits frequently cloak the valley-slopes continuously, extending from the plateau above down to the modern alluvium of the river, underneath which they pass. They thus overlie the gravels and sands, the one series being as a rule sharply marked-off from the other. Their origin has been much discussed by geologists, who are far from being agreed on the subject. The deposits in question differ in character, and cannot all have been formed in the same way. In many cases there can be little or no doubt that they are of the nature of flood-accumulations—being, like the gravel and sand beds, true river-formations. But in other cases they would appear to have had quite a different origin.

Although the river-drifts of England and France have been carefully studied for many years, it must be admitted that the precise succession of events chronicled by these drifts has not yet been definitely ascertained. The recent researches of M. Commont in the valley of the Somme, however, have thrown much needed light on the subject. He has succeeded in unravelling the structure and discovering the true succession of the Pleistocene deposits of that famous

region, and his results cannot but have a far-reaching influence. It is interesting to reflect that the river-drifts of the Somme valley were the earliest of the kind to attract the attention of geologists and archæologists. This was due to the discoveries made many years ago by an enthusiastic French antiquarian, Boucher de Perthes, to whom must be assigned the merit of having been the first to direct the attention of the scientific world to the occurrence of human implements associated with remains of extinct animals in beds of undisturbed Pleistocene gravel and sand. It was not, however, until after cave-explorations had convinced geologists of the antiquity of man, and his contemporaneity with the Pleistocene mammals, that the importance of the discoveries in the Somme valley was realised.

Over fifty years have elapsed since then, and it need hardly be said that in the interval our knowledge of river-drifts has greatly increased. So abundant is the evidence, indeed, that even the briefest summary of the more important phenomena would occupy the time of many lectures. The most I can attempt at present is to sketch in outline the more notable features of the evidence furnished by certain typical or representative valleys. The full meaning of that evidence, however, will not appear until we have attained a comprehensive view of the Pleistocene formations as a whole. When we have learned what these have to tell us of the climatic and geographical conditions of Europe during Pleistocene

times, the significance of the evidence we are about to consider will become more apparent. Nevertheless, apart from that wider outlook which we may hope to gain, the phenomena of the old river-drifts have yet an intelligible tale to unfold, which may be followed without reference to the collateral evidence supplied by other Pleistocene formations.

Within the last few years the river-drifts of the Somme have again claimed the special attention of geologists and archæologists on account, as I have said, of the remarkable results obtained by M. Commont, some account of which must now be given. The valley of the Somme has been excavated in chalk, the surface of which is of course largely concealed under river-drifts of one kind or another. At relatively high levels, however, the bare chalk appears, forming short and relatively abrupt slopes. These, as Professor Prestwich showed long ago, are the frontal edges of platforms of erosion. The drifts lying on such a platform at a considerable elevation constituted his "high-level" series, while those occupying the bottom of the valley formed his "low-level" series. Where no such high-level platform was visible, he had necessarily some difficulty in distinguishing between one series and the other—their relative height above the river, rather than any distinguishing characters of the drifts themselves, determining whether they should be classed as "high-" or "low-level."

For a number of years M. Commont has with

great zeal worked out the structure of the drifts of the Somme valley, and shown that the continuity of the valley-slopes is interrupted by three successive platforms of erosion, which, although often cloaked and concealed by the drifts, he has yet been able to follow by means of borings and openings of one kind and another. (See Fig. 6.) The uppermost terrace occurs at a height of about 100 feet above the Somme, the middle terrace at about seventy feet, while the lowest, beginning at a height of forty feet, passes underneath the river. Beds of fluviatile gravel and sand rest upon these platforms of chalk—to which indeed they are confined. The deposits of each of the three terraces have yielded artifacts—the middle terrace being much the richest repository. The lowest terrace is for the most part inaccessible, passing as it does under the modern alluvium of the river; a few artifacts, however, have been obtained from it. In the highest terrace implements rarely occur. It is important to note that all the artifacts met with in the gravels and sands of the terraces are Chellean—the most primitive forms occurring in the coarse gravels that repose immediately upon the chalk, while the better formed artifacts of the same type seem to be restricted to the overlying sands.

Since Chellean artifacts occur upon all three terraces, it is clear that the excavation of the Somme valley must have been practically completed in early Pleistocene times. The Chellean stage is thus shown to have been of prolonged duration, for however rapidly

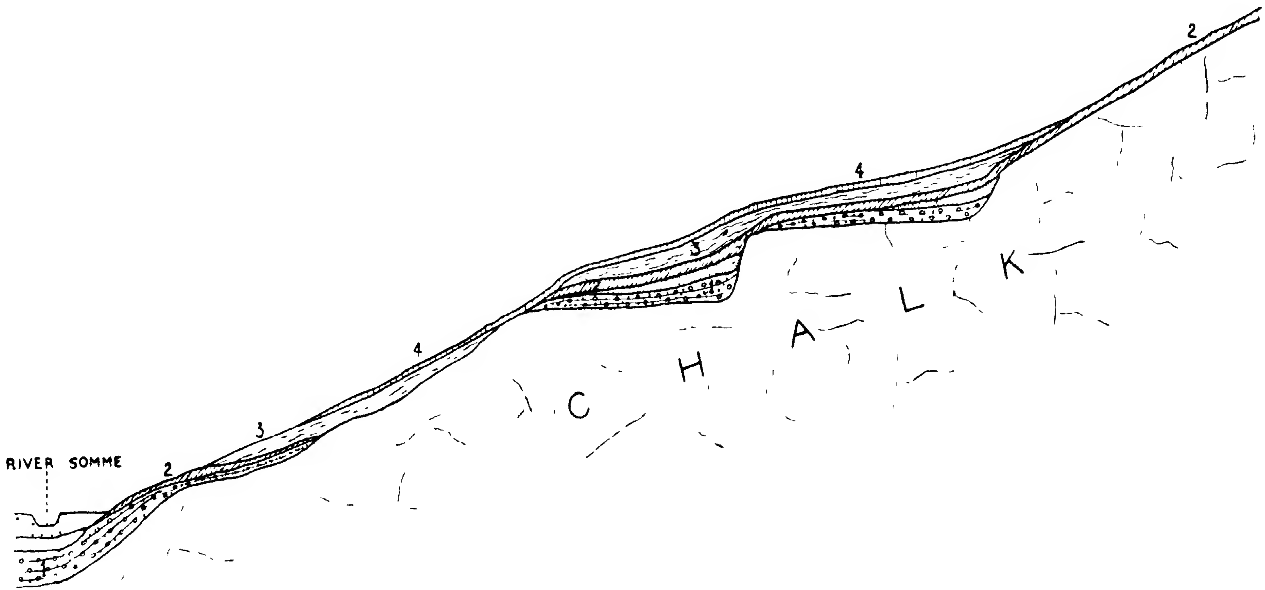


FIG. 6.—SECTION OF DRIFT-DEPOSITS IN VALLEY OF THE SOMME. (After M. Commont.)

1, Alluvial gravel and sand on terraces of erosion; 2, *limon fendillé*; 3, *ergeron*; 4, recent "brick-earth."

the Somme may have lowered its bed, it must nevertheless have taken a very long time indeed to have deepened its valley for more than 100 feet.

The loams and brick-earths are of later age than the gravels and sands of the terraces, which they overlap and conceal—extending more or less continuously from the highest levels down to the bottom of the valley. They differ in origin from the terrace-deposits which, as we have seen, are river-accumulations. The loams and brick-earths, on the other hand, are somewhat of the nature of rain-wash, and consist of materials which have come down from the adjacent plateaux and hill-slopes. They show traces of bedding, often indicated by lines and layers of angular gravel, but these dip directly down the valley-slope. Not only are they thus steeply-inclined, but they often contain land-shells and plant-remains. All the appearances they present, in short, are suggestive of the action of surface-waters, such as rain or melting snow, which have carried away and re-arranged over the flanks of the hills and the sides of the valley, the loams and other residual products resulting from the long-continued weathering of the chalk.

M. Commont shows that in the Somme valley there are three separate and distinct "loams," one overlying the other. The lowest and oldest (*limon fendillé*) is characterised by the presence of Acheulian artifacts, while the overlying loam (*ergeron*) with its associated angular gravels, contains Mousterian implements — Magdalenian artifacts appearing only

towards the top of the same accumulation. The uppermost or superficial loam, on the other hand, is a brick-earth of quite recent origin, due partly to the washing of rain, and partly to the weathering of the immediately underlying deposits. M. Commont's results, therefore, are highly important in several respects. In the first place, they confirm the evidence of the caves as to the succession of the several archæological stages from the Chellean to the Magdalenian—the only stages not represented being the Aurignacian and Solutréan. In the second place they lead us to believe that when the river-drifts of such great valleys as those of the Seine and the Thames have been as assiduously investigated, they also will show a definite succession of stages.

In my first lecture I made reference to the calcareous tufa of La Celle, near Paris. In the section (Fig. 9, p. 233), copied from one by Professor Obermaier, the position of that particular tufa in the Pleistocene series is clearly indicated. The gravels A may safely be assigned to the warm Chellean stage, while the over-lying tufa shows the passage from that very genial stage to the succeeding cooler conditions of Acheulian times.

The tale told by the Pleistocene deposits of the Thames valley, although not quite so clear as that obtained by M. Commont from his researches in the valley of the Somme, is yet full of interest to archæologists and geologists alike, for they have yielded many organic remains and an abundant

harvest of artifacts. The mammals represented agree generally with those recorded from our cave-accumulations, and we may safely conclude therefore that the old river alluvia and the cave-deposits are approximately of the same age. Among the species we note hippopotamus, broad-nosed rhinoceros, and straight-tusked elephant—members of the southern group—as well as notable members of the northern group, such as reindeer and musk-ox. Only now and again, however, do these strongly contrasted faunas occur at separate and distinct horizons in the alluvia. Very frequently the remains are commingled, and this formerly led to the belief that great seasonal migrations had taken place—the hippopotamus and its congeners wandering north in summer, and the reindeer and its associates coming south in winter, so that the same area was occupied alternately during the year by the two faunas. That view, however, has been abandoned, and geologists now recognise that the intermingling of mammalian remains in the Pleistocene alluvia is most probably due to the conditions under which such alluvia are deposited. Rivers are constantly cutting into and redistributing their accumulations, so that any organic relics they may contain are liable to be disinterred and reburied, side by side it may be, with others belonging to a later date. Not only so, but now and again an active river will trench its gravels more or less extensively and again fill up the excavations it has made. In this way sand and gravel have become banked against

similar deposits of greater age, and the line of junction between the two sets of beds cannot always be recognised — the one sometimes seeming to shade into the other. But let it be noted that where no such disturbances of the bedding have taken place—where the alluvia have obviously been regularly accumulated, bed above bed, their mammalian remains are found to belong usually to one and the same fauna—sometimes to the southern and temperate group, sometimes to the northern. And the same is the case with the shells enclosed in the alluvia. Now and again, for example, these represent species which no longer live in English rivers (*Corbicula fluminalis* and *Unio littoralis*) but in those of more southerly latitudes. On the other hand, the shells present in undisturbed alluvia are frequently indicative rather of cold-temperate, or even of arctic conditions, and a similar tale is told by the plant-remains.

It would thus appear that the river-drifts in question are the records of a long period of time, during which considerable climatic changes supervened. The length of the period is indicated not only by those climatic revolutions, but by the enormous amount of work done by the Pleistocene rivers. The formation of the gravels with their associated beds of sand and loam must have been a protracted process, for they not only attain a great thickness but overspread broad areas. In short, all the phenomena of the drifts themselves, not to speak of the modifications of surface experienced by the wide regions traversed

by the valleys, demonstrate how great has been the denudation of the land since it was first visited by Palæolithic man. And all that denudation — the excavation of the valleys and the lowering of the land-surface—it must be remembered, was practically completed before the apparition of his Neolithic successor. It is not too much to say that the modification of surface effected since the beginning of the New Stone age is too inconsiderable to be noticed, when one thinks of the great changes brought about during the preceding Palæolithic period.

The Pleistocene river-deposits—the gravels and sands — occasionally appear in the valleys of the Thames and its tributaries as tolerably well-defined terraces, rising one above another. More frequently, however, this terraced aspect is obscure. Nevertheless we can hardly doubt that the gravels were deposited during the gradual excavation of the valley, so that those occurring at the higher levels must be the oldest. The associated loams and brick-earths often overlap the gravels, and consequently extend to a higher level. The latest of these loamy accumulations are certain overlying tumultuous sheets and heaps of earthy materials and angular gravels, which spread downwards from the heights overlooking the valleys.

The oldest river-deposits of the Thames have yielded remains of the southern and temperate group of mammals (hippopotamus, broad-nosed rhinoceros, straight-tusked elephant, mammoth, deer, horse, lion, etc.), but no definitely arctic types, for the mammoth

had a wide range, and although chiefly associated with northern forms, seems not infrequently to have invaded the provinces occupied by the temperate and southern species. *Corbicula fluminalis*—a southern shell—appears in the same deposits, while man is represented by artifacts of types characteristic of the earlier culture-stages—Chellean in the lower beds, Acheulian higher up.

The river-drifts of somewhat later age are of particular interest. From them have come immense quantities of implements all belonging apparently to the Mousterian culture-stage. It is notable that among these later river-deposits several old land-surfaces have been discovered. These are known as "Palæolithic floors," and consist of a few inches of angular gravel, crowded in places with unabraded implements and flakes, which obviously occur just where they were left by the Palæolithic workmen. One such floor has been traced by Mr Worthington Smith over a wide area. He believes it must formerly have extended throughout East Middlesex into Herts as far as Hertford and Ware, and on both sides of the Thames from London to the Nore. Plant-remains occur plentifully on that old land-surface, but they are often so fragile and badly preserved that their determination is not always possible. Impressions of portions of leaves, and stems of grass, rushes, and sedges are not uncommon; and birch, alder, pine, yew, elm, and hazel have been recognised. The common male fern is of frequent occurrence, while

the royal fern (*Osmunda regalis*) is present in such profusion as to suggest that the fronds might represent the litter or bedding on which the Mousterian savages had rested. Upon the whole, therefore, this assemblage of plants indicates a temperate climate. That conclusion is not gainsaid by the mammalian remains occurring in the brick-earth, which, although they include mammoth and reindeer, are chiefly of temperate types. (See NOTE 7.)

The drift gravels we have hitherto been considering occur at relatively high levels—seventy to eighty feet above the sea—and belong, therefore, to the oldest series of Pleistocene alluvia. Of younger age are the low-level gravels that appear at heights of forty feet and less above the sea. Amongst these Mr S. H. Warren recently discovered in the valley of the Lea an arctic plant-bed, that varied from one to two feet in thickness. It occurs at a depth from the surface of fifteen to seventeen feet, and is sometimes exposed in continuous section for twenty or thirty yards. Among the plants recognised are a number of alpine-arctic mosses, now either entirely extinct in Britain, or confined to the summits of the higher Scottish mountains, while all the remaining species are just such as might at present be seen flourishing in the arctic mainland of Europe. The testimony of the accompanying shells agrees with that of the plants, for they indicate a climate like that of Lapland or southern Iceland. The low-level valley-gravels in which this notable plant-bed occurs have yielded

remains of mammoth, woolly rhinoceros, reindeer, horse, ox or bison, lemming, etc., but the only human implements met with are *remanié* forms—that is to say, they have been derived from the higher and older terraces.

A long interval must have elapsed between the deposition of the high-level gravels and the formation of these low-level deposits. This is at once indicated by the fact that the latter only began to be formed after the river had gradually deepened its valley by some sixty or seventy feet below the level at which it had flowed when the Mousterian tool-makers wandered along its shores.

That cold climatic conditions supervened subsequent to the formation of the high-level gravels and brick-earths has been known for many years. Almost everywhere these deposits are overlaid by amorphous materials, underneath which the river alluvia are much disturbed, flexed, folded, and contorted. These are the phenomena known to geologists as "Trail," and they are well exemplified and explained by the so-called "flowing soils" of high arctic latitudes. In such regions the frozen soils and subsoils, when exposed to the heat of the sun in summer, tend to become semi-fluid and to creep and flow more or less sluggishly down the slopes. In the London district sheets and masses of similar origin, creeping outwards from the heights into the valleys, have ploughed their way into the old river-drifts, and everywhere produced much confusion. Embedded at all

angles in this muddy or earthy material are found abraded and whitened flint implements, which have all the appearance of having been long exposed to the weather, and were doubtless caught up and carried down from the old land-surface that overlooked the valleys. These remarkable sheets of "contorted drift" represent the closing stage of the Palæolithic period, so far as the valleys of the Thames and its tributaries are concerned. No Palæolithic relics occur in any deposits that may chance to overlie the "contorted drift"—the oldest artifacts met with in any such younger undisturbed formations are of Neolithic age.

Thus the evidence, so far as I have traced it, would seem to show that certain high-level river-gravels were deposited at a time when the climatic conditions were upon the whole temperate; while arctic conditions prevailed during the accumulation of the low-level alluvia. But, as already indicated, the high-level gravels contain now and again large stones and blocks which could not have been transported by river-action alone, but have apparently been carried by ice-rafts. Now and again, also, the alluvia have yielded relics of the northern mammalian fauna, as reindeer, woolly rhinoceros, and mammoth. But the testimony of these remains is so far negatived by the occurrence in the same deposits of characteristic temperate forms. This commingling of discordant faunas is probably largely due to the mode of formation of the beds in which the remains occur. Nothing

is more difficult, as Lyell long ago recognised, than to settle the chronology of fluviatile deposits. "It is almost equally difficult," he remarks, "to avail ourselves of the evidence of organic remains or of the superposition of the strata, for we may find two old river-beds on the same level, in juxtaposition, one of them perhaps many thousands of years posterior in date to the other." For all that we can tell, therefore, there may have been several oscillations of climate during the gradual accumulation of the high-level alluvia. It is enough, however, for our present purpose to realise the fact that the oldest alluvial deposits are characterised by the presence of the southern and temperate group — while the accompanying human relics are among the most primitive recognised by archæologists.

The low-level gravels, on the other hand, which must be many thousands of years younger than those of the higher level, were unquestionably accumulated under very cold conditions. The plant-remains indeed leave us in no doubt that at the time of the formation of the low-level terrace of the Lea valley, southern England must have been a region of tundras. Hitherto no evidence is forthcoming to show that man was an occupant of our country at that epoch. From the Pleistocene alluvia of the London district, therefore, we cannot as yet educe a complete consecutive history. They tell us of a Thames, the bed of which in early Palæolithic times was considerably more than 100 feet above that of the modern river.

Through the long Pleistocene period it continued slowly to deepen its valley—at one time flowing as a broad placid stream, now and again as a torrential river, rising high above its ordinary level and flooding extensive regions. And thus as the erosion proceeded, the slopes of the gradually deepening valley became mantled with gravel and swathed in broad sheets of flood-loam. When the river had sunk its channel some seventy feet below its earlier bed, a very cold climate supervened; the land was then sparsely clothed with arctic mosses and dwarf willows and birches, while ever and anon moving masses of mud and stones made their way into the valley from the heights above. And with this picture of arctic conditions we reach the end of the Pleistocene story, so far as that is revealed by the old alluvia of the Thames. The excavation of the valley, as already remarked, had been practically completed long before Neolithic man appeared upon the scene.

Having now shortly outlined the more important evidence derived from the old river alluvia of France and England, we may next briefly consider some of the most significant phenomena displayed by the valleys of middle Europe, and for this purpose it will suffice to confine your attention to one particular kind of valley-drift, which, although not unknown in western Europe, yet attains its most conspicuous development in the central region of the Continent. The evidence I have cited from the river-drifts proves that Palæolithic man was contemporaneous in western Europe

sometimes with the southern and temperate mammalian group, and at other times with the northern forms. Did time suffice I might adduce similar evidence from the river-deposits both of central and southern Europe; but I shall content myself by describing very shortly the peculiar formation known to geologists as löss.

Loess is certainly one of the most remarkable superficial accumulations of central and west central Europe. Typically it is a fine-grained, yellowish, calcareous, sandy loam, consisting very largely of minute grains of quartz, with some admixture of argillaceous and calcareous matter. Upon the whole the quartz-grains are well rounded, although often enough sharply angular. Frequently the accumulation shows a porous structure, and is penetrated by long, approximately vertical root-like tubes or canals, lined with calcareous matter, which cause the deposit to cleave or divide in vertical planes. Hence it usually forms upright bluffs upon the margins of streams or rivers which intersect it. It is usually unstratified, except now and again towards the bottom of the deposit, where intercalated layers, and sometimes even thick beds of sand, make their appearance. The loess is essentially a deposit of the low grounds, and is well developed in the broad river-valleys of western and central Europe, as in those of the Seine, the Garonne, the Rhone, the Meuse, the Moselle, the Rhine and its tributaries, the Danube and many of its affluents, such as the Drave, the Save, the Morava, and the Theiss. It also extends

as a narrow belt along the southern margin of the great plains of north Germany. It is in southern and south-eastern Russia, however, where it attains its widest development, covering as it does an immense tract between the valleys of the Pruth and the Volga. Throughout this vast region it is usually very dark in colour, forming what is known as the Black Earth.

I shall not at present consider the source of the materials of which the loess is composed. It is obvious enough that the accumulation has in some places been arranged by water. Thus here and there, especially at or towards the bottom of the deposit, distinct traces of bedding may be seen, and the beds have yielded fresh-water shells. This, however, is exceptional. Loess is, for the most part, a subaërial accumulation —a wind-blown deposit. This is shown not only by the rounded character of its minute constituents and by the general absence of bedded arrangement, but by the abundant presence of land-shells and the frequent occurrence of mammalian remains. Its organic contents are essentially terrestrial. Moreover, its particular distribution—the mode in which it occurs —points clearly to the action of prevalent winds. Thus, although it is widely developed over low-lying regions, it nevertheless sweeps up to heights of 200 to 300 feet and more above the bottoms of the great river-valleys. Not only so, but ever and anon it extends across the hills and plateaus between adjacent valleys, wrapping the whole land, in short, like a mantle. Again, in many places, we find it heaped up in the

lee of hills, the exposed windward slopes of which bear no trace of it, while in certain valleys it shows a similar partial distribution.

Among the organic remains yielded by the loess are some that indicate arctic conditions, while others are strongly suggestive of a steppe climate, and yet others tell us of forest lands. It is impossible that all the creatures referred to could have lived side by side in the same region, and annual migrations will not wholly explain their appearance in the same deposit. The evidence leads to the conclusion that the accumulation of the loess must represent a long period of time during which climatic changes took place. Fortunately now and again the loessic accumulations exhibit a succession of faunal zones—different suites of organic remains occurring at different levels. And a similar and corresponding succession has been discovered in not a few caves in middle Europe.

A tundra fauna is the earliest of which we have any record in the loess. In my first lecture I gave a general account of that fauna and its former distribution throughout what are now the temperate latitudes of our Continent. It ranged, as you may remember, from Russia as far west as England, and from northern Germany south to the forelands of the Alps—its remains occurring not only in caves, but often abundantly in loess. In the latter, just as in the rock-shelter at Schweizersbild, the remains in question are most plentiful towards the bottom of the deposits, and gradually become less numerous in the beds above,

until they finally disappear. Before the last trace of the arctic forms has vanished, however, relics of the steppe fauna begin to occur, and eventually predominate. In a word, there was no sudden dying-out of one fauna and precipitate appearance of another, but a gradual replacement, consequent doubtless upon changing climatic conditions.

One of the notable characteristics of tundra and steppe climates, let me remind you, is the frequent occurrence of tempestuous winds and blizzards, during which much destruction of animal life may take place. Abundant evidence is forthcoming to show that the wild animals of our prehistoric steppes and tundras were often done to death in their hundreds and thousands. Again and again immense heaps and accumulations of their skeletal remains have been encountered in the loess—appearances strongly recalling the similar bone-finds of Siberia and North America. The deposits in which the European bone-finds occur are of wind-blown origin, and we seem justified, therefore, in concluding that the animals perished in snowstorms. In these low latitudes, however, we could not expect to meet with ice-formations like those of Siberia. That drifted snows did formerly accumulate in middle Europe, however, and were preserved for long periods under coverings of sand and other materials, we have good reasons for believing. Indeed, even at the present day the drifted snows in south-east Russia are occasionally buried under sand and so persist for years.

In one case recorded by Borszcoff, what appeared to be an ordinary sandhill proved to be a mass of congealed snow cloaked in sand about a foot in thickness. Immediately under the surface the snow was granular and névé-like, but a little deeper it was firm and solid ice. This was in one of the tributary valleys of the Ilek, in the steppes south of Orenburg, about the 50th parallel—a relatively dry region. If snow can be thus preserved in a low-lying region so far south, we may readily conceive how in the steppe epoch of middle Europe snow-drifts similarly protected might now and again have persisted for years. But it was during the preceding tundra epoch that this would be most commonly the case. And much interesting evidence is forthcoming to show that in many places thick sheets of congealed snow did accumulate and become buried and preserved at that time. In a subsequent lecture I shall give some account of the so-called "rubble-drifts" of central and southern Europe. For the present, however, I need only say that the drifts in question consist of rock-rubbish, which has moved down gentle hill-slopes and spread itself over adjacent low grounds—phenomena that indicate the former presence of deep snow-drifts, in and upon which the rocky debris travelled. These were not glaciers, but merely sheets of snow and névé, charged with and covered by earthy matter and rock-fragments, and set in motion in spring and summer when thaw ensued. The occurrence in the earthy debris of

bones of the reindeer and other Pleistocene mammals shows that the deposits belong to prehistoric times.

Again, certain phenomena connected with the river gravels of the same period lead to the conviction that the drainage was often interfered with by snow-drifts. As Mr Darwin suggested to me many years ago, the river valleys would seem to have become filled in places with alternate sheets of congealed snow or ice and layers of gravel and shingle. Long afterwards, when the interbedded strata of ice melted slowly away, the associated river detritus settled quietly down, and owing to the differential movement of the subsiding materials, the longer stones arranged themselves in lines of least resistance—so that now we find them most usually standing on end in the gravel beds. (See NOTE 8.)

Thus, apart from the evidence supplied by the bone-accumulations of the loess, we may reasonably infer that snow-drifts were of common occurrence in middle Europe in prehistoric times. Doubtless most of the snow which covered the plains of our Continent in winter melted and disappeared in summer, just as is the case in the tundras and steppes of our own day. The carcasses of animals that may have perished in blizzards would thus most frequently become uncovered in spring, to be devoured by hyænas, wolves, and bears, and the disarticulated skeletons might often be bleached and weather-worn before they were finally buried in loess. Nor was it only in plains and open valleys that sudden death may have

overtaken large numbers of animals. In tundras and steppes alike the wild and semi-wild denizens of the plains seek refuge from the drifting snow in the fissures, caves, gullies, and ravines of the hills and mountains, where they are sometimes frozen to death or smothered. Herbivorous and carnivorous animals thus often perish together, for in the presence of a common danger, whether it be prairie or forest fire, or flood or blizzard—natural antipathies and animosities are in abeyance, and all alike struggle to escape.

Man, as I have mentioned, lived in middle Europe in tundra times, and we have abundant evidence of his presence there throughout the succeeding steppe epoch. Again and again human relics have been met with at all levels in the loess throughout central Europe. Thus in the valleys of the Danube and some of its tributaries, they have been discovered in undisturbed loess at depths of from 20 to nearly 100 feet from the surface. Not a few of these finds evidently represent old prehistoric camping stations—marked by the presence of quantities of charcoal and ashes, burnt and calcined bones, together with worked flints, bones, and ivory. Among the animal remains are those of mammoth, woolly rhinoceros, musk ox, reindeer, elk, horse, lion, glutton, bear, wolf, arctic fox, common fox, and hyæna.

In concluding this brief review of the tale told by the alluvial and æolian deposits of the Pleistocene, I may remark that while this tale clearly supplements that of the cave-accumulations, it nevertheless does

not give us a complete history of the period. It is true I have omitted all direct reference to certain geographical changes which may be inferred from some of the phenomena we have been considering. For instance, I might point out how the distribution of Pleistocene faunas and floras is indicative of considerable changes in the relative level of land and sea. At one or more stages of the period notable land-bridges must have connected Europe with Africa across the Mediterranean. It was doubtless by such connections that the southern mammals invaded our Continent, and the former presence of the same species in Britain likewise bespeaks a union between our islands and the Continent. At various epochs of the Pleistocene period Palæolithic man might have walked dry shod from Africa into Europe, and across what are now the English Channel and the North Sea into Britain. But the evidence for such changes is not derived only from the geographical distribution of the Pleistocene animals and plants, and I prefer, therefore, to pass from the subject for the present. In a later part of this course I shall return to it after having discussed the evidence supplied by the glacial formations.

Just one other point, and I have done. It must be kept in view that the river alluvia containing relics and remains of Palæolithic man and his congeners occur for the most part in middle and southern Europe. In Britain they are hardly met with north of the Thames valley, and they are similarly absent

from the corresponding latitudes on the Continent. But we encounter them in all the great valleys of middle and southern Europe. It is quite otherwise with the younger alluvia containing relics of Neolithic man. These may be said to appear in every latitude from the extreme north to the extreme south of Europe, and from the shores of the Atlantic indefinitely eastwards.

LECTURE V

THE TESTIMONY OF THE GLACIAL FORMATIONS

I.—*Glacial Action*

Glacial Action. Formation of Screes. Flowing Soils of Arctic Regions. Breccias of Gibraltar, their Character and Origin. Alpine Glaciers. Ice-cap Glaciers of Norway. Arctic and Antarctic Ice-sheets. Geological Work of Glaciers and Ice-sheets. Superficial and Ground- or Bottom-Moraines Rock-basins and other Evidence of Glacial Erosion. Over-deepening of Valleys by Glacial Action.

In preceding lectures I have discussed the general phenomena of the Pleistocene cave-accumulations and river alluvia with their relics and remains of man. From the study of these we have learned something not only of prehistoric man himself, but of the climatic conditions under which he lived. We have seen that for some time at least he hunted the reindeer in the south of France, when a large part of what is now temperate Europe must have been a dreary tundra—a region clothed with an arctic-alpine flora; swathed in snow during winter, subject to severe storms and blizzards at the changes of the seasons; and to excessive floods in spring and summer. Reflecting upon all this we naturally

ask :—What relation do the cave-accumulations and river-alluvia bear to the glacial formations? Did Palæolithic man live in Europe before, during, or after the Ice Age? Obviously to satisfy ourselves on this point, we must devote attention to the records of that age; for we are well assured that the glacial formations belong to the Pleistocene period—to that period, in fact, when Palæolithic man first appeared in Europe.

These formations present us with so many complex phenomena—so many difficult problems are suggested by them—that before entering on their consideration I think it well to devote this lecture to the study of existing glacial action. The present, as geology insists, is the only key to the past, and at the risk of wearying those who may already be familiar with glacial phenomena, I can hardly avoid describing such as seem to bear most directly on the origin of the Pleistocene glacial accumulations. Glacial action is a somewhat comprehensive term, however, for it signifies not only the work of glaciers or ice-rivers, but that of frost and snow, which, as we all know, may characterise regions where no glaciers exist. As these several kinds of ice action must have operated in Pleistocene times, it is necessary that we should understand how they work and what they can do.

First, then, let us consider the action with which we are most familiar—that of frost. Frost pulverises our soils and causes rock-surfaces to crumble down.

The *modus operandi* is simple enough. All rocks are more or less porous, and thus tend to absorb water, which when it freezes causes their constituent particles to separate. Again rock-beds and rock-masses of every kind are traversed by natural division-planes, along which water makes its way from the surface. When water freezes in the joints and fissures these are of course suddenly widened—in a word, the rocks are disintegrated and ruptured, and when thaw follows, the loosened particles, blocks, and fragments tend to fall asunder. In temperate latitudes like ours the results of this action are most conspicuous at high elevations, where the naked mountain-tops are often entirely concealed under their own ruins. Should rupturing take place in cliffs or upon steep slopes, the debris shoots downwards, either to accumulate in heaps below, or to cloak the declivities with rough sheets or "screes." Nor does the process of destruction stop here, for the screes are themselves attacked—their rock-fragments being further disintegrated and ruptured. In this way much of the material eventually becomes reduced to a kind of rough gravel, grit, and earth, that sinks or is washed down between the larger blocks. During heavy rain the debris may be saturated to such an extent that not infrequently it creeps and flows down hill; and the same movement often takes place when the snows are melting in spring.

It will be readily understood that the phenomena described attain a great development in arctic regions.

Frozen hard during winter and covered with thick snow, the screes in those regions remain steadfast till summer returns. Then the snow melts, the earthy debris thaws, becomes semi-fluid, and moves sluggishly downward—frequently spreading far out over low-lying and relatively level or gently-inclined ground. The movement may be arrested at night by the freezing of the sodden material. Even then, however, motion does not at once cease, for while freezing goes on expansion takes place, and the masses are compelled to move in the direction of least resistance—that is, of course, down hill. Similar phenomena have been observed at high elevations in temperate regions; certain valleys in the Rocky Mountains, for example, are thickly covered with earthy debris which, when the snow melts on the mountains, becomes saturated and creeps slowly forward. Hedin, the famous Swedish explorer, has given a graphic description of the great moving sheets of water-saturated detritus of the Tibetan highlands, which his caravan had the utmost difficulty in crossing.

It may be remembered that in my last lecture I referred to the "flowing soils" of Arctic regions as helping us to explain the origin of those remarkable sheets of confused earthy and stony materials that are so frequently associated with the ancient alluvia of Pleistocene times. In all parts of Europe formations of the kind occur, in illustration of which I may give a short account of the massive breccia or solidified rock-rubble of Gibraltar.

The Rock of Gibraltar, as everyone knows, is a narrow arête or sharp ridge, that trends nearly due north and south. At its north end it terminates in a steep wall-like front, some 1350 feet in height. On the east side the declivities are hardly less precipitous, while on the west the gradients are not nearly so steep. The culminating point of the ridge reaches about 1400 feet above the sea. As regards the geological structure of Gibraltar, all that need be said is that the ridge coincides with the outcrop of a thick limestone or series of limestone-beds that dip towards the west at a high angle, so as to pass under certain dark shales which make their appearance towards the base of the Rock. The overlying breccia is a confused aggregate of angular fragments and blocks of limestone, embedded in a matrix of calcified grit and earth—the whole accumulation forming a mass as solid as the limestones over which it has been spread. It varies in thickness from a few feet up to thirty or forty yards, being thinnest and occurring only in patches on the steeper slopes of the Rock, but thickening out upon the lower grounds, as it approaches and enters the sea. It has manifestly been derived from the breaking-up of the limestone, for it contains no stones foreign to the place.

That the breccia is no longer forming becomes obvious at a glance. Everywhere it has been worn, furrowed, and trenched by rain and torrents, in precisely the same way as the limestone where that is exposed. In short, the breccia presents the roughly

corrugated surface characteristic of calcareous rocks which have been long subjected to the chemical action of rain. The red earth or insoluble residue has as usual collected in the numerous irregular grooves and hollows of the rugged surface. In further proof of the great antiquity of the breccia, it may be mentioned that long after it had become thoroughly consolidated, subsidence of the region supervened and the Rock of Gibraltar was partially submerged. Under those conditions the sea carved out certain well-marked horizontal terraces which are seen traversing the face of the Rock. These old sea-margins, it may be noted, have been hewn sometimes in limestone, sometimes in consolidated rock-rubble or breccia.

All the appearances presented by the breccia lead to the belief that it is an ancient scree due to the action of frost and thaw. Only severe frost, indeed, could have wedged out the larger blocks in the mass, some of which measure several yards in diameter, and must weigh twenty or thirty tons at least. The larger blocks and smaller fragments are all alike sharply angular, which would not have been the case had the accumulation owed its origin to waves and breakers. Nor can it be due to the action of torrents. Torrents might have swept down small fragments to the base of the Rock, but they could hardly carry these and still less the larger blocks across the low grounds, for a distance of 500 or 600 yards, over which the inclination of the ground is not

more than 8° or 9°, and in places does not exceed 2° or 3°.

How then was the debris spread over those low-lying areas? Frost might well rupture and shatter the limestones of the ridge, and the steep slopes of the Rock might be sprinkled with fragments and covered with screes, formed in the usual way. We may even admit that the impetus acquired by blocks detached by frost along the summit of the Rock might suffice to bring these down the more abrupt declivities, but it could not possibly transport them across the low grounds to the sea. The most reasonable explanation of the breccias is at once suggested by the arctic phenomena of "flowing soils and debris" to which some reference was made in my last lecture. Gibraltar, where at present frost is unknown, would seem formerly to have experienced severe winters, when the limestones along the crest of the arête were broken up and shattered. At that time heavy snow may well have swathed the flanks of the Rock and extended over the low grounds. Under such conditions scree materials, slipping and rolling down, would be scattered over the snow-covered slopes, and possibly snow-shoots or avalanches might now and again occur. Judging from what takes place in many high mountain tracts, there might even have been a slow downward movement of snow and névé with much included rock-rubbish. In one way or another heaps of commingled snow and debris would tend to collect

about the base of steep declivities and precipices. With the return of spring and summer the snow would melt, and the sodden rock-rubbish would then move sluggishly forwards like the so-called "earth-glaciers" of the Rocky Mountains.

The limestone-breccias of Gibraltar are only one of many similar ancient sheets and heaps of rubble that were abundantly developed in Pleistocene times throughout Europe. The distinguishing character of these old screes is their worn and denuded aspect. No longer in the process of formation, they are gradually being worn and wasted away. Moreover they frequently make their appearance in regions where, as at Gibraltar, frost and snow are at present unknown.

But of more importance to the student of Pleistocene geology is the action of true glaciers or ice-rivers. Everyone is familiar with the fact that in the Alps and other regions where glaciers occur there is a line above which more snow accumulates than is melted or evaporated. Needless to say the snow cannot augment in thickness to an indefinite extent. From abrupt declivities great shreds are constantly dropping away as avalanches, but however extensive and numerous these may be, they do not suffice to drain the vast supplies of snow which collect in the profound amphitheatrical recesses of the mountains. This work is effected by a regular system of ice-rivers. At low temperatures snow is dry and powdery. When the temperature rises

melting begins, and drops of water set free at the surface sink into the subjacent layer, where they again freeze, forming envelopes around the snow crystals. Eventually all the snow becomes in this way granular, the air being partially expelled in the process. At the same time the pressure exerted by the accumulating snow tends still further to squeeze out the air entangled in the underlying opaque névé, which thus gradually passes into the condition of transparent ice. The ice now begins to creep outwards from the capacious cirque in which it originated, and makes its way downward, flowing very much as if it were a viscous body. Shortly after starting on its journey, it may be joined by similar flows proceeding from adjacent cirques. The young glacier thus developed may eventually coalesce with one or more ice-streams coming from tributary valleys, and as it descends to lower levels may itself become the tributary of some great trunk glacier, formed by the union of many smaller ice-flows.

The movement of a glacier is differential—it is greatest about the middle or centre of the flow, but decreases towards the sides and bottom, where the motion is retarded by friction. The rate of movement varies; in small glaciers it may be only a few inches up to a foot or so in a day, but in very large ice-flows, such as those of arctic regions, it sometimes exceeds fifty feet in twenty-four hours. The rate depends partly on temperature, partly on the inclination of the ground, and partly on the volume of the

ice. Hence the motion is greater in summer than in winter, and during day than during night. Again, other things being equal, a glacier moves more rapidly on a steep than on a gentle slope; while very thick ice-streams flow faster than glaciers of relatively insignificant dimensions.

The glaciers to which I have been referring are typically represented by those of the Alps—the distinguishing character of which is that they have their source in deep mountain-recesses whence they make their way down mountain valleys. But there are other types of ice-flow of great interest, especially from a geological point of view. These may be called ice-cap glaciers, of which excellent examples are seen in Norway. The configuration of that country differs essentially from that of the Alps. In the latter we have a complicated series of mountain-groups and crested ranges, everywhere overlooking the profound cirques and deep valleys in which glaciers are generated. Norway, on the other hand, is a lofty plateau, deeply trenched, it is true, by mountain valleys and fiords, but showing between these depressions extensive tracts with a relatively flat or undulating surface, which are often not dominated by peaks or ridges. Upon these plateaus snow accumulates, becomes granulated, and passes into ice, just as in the Alpine cirques. In short, lenticular ice-caps or sheets are formed, which attain their maximum thickness about the centre, whence they thin away as the outskirts of the plateaus are

approached. The ice, it need hardly be said, is not passive but flows outwards in all directions. Here and there it projects longer or shorter tongues or lobes into valleys; in other places, where no valleys are present, the ice-sheet may terminate in a continuous ice-wall on the verge or brink of a fiord.

The essential features of a Norwegian ice-cap are repeated, but on a much larger scale, by the great "inland-ice" of Greenland. There is good reason to believe that Greenland, like Norway, is a tableland. With the exception of a narrow marginal strip the whole country is covered by a vast dome-shaped ice-sheet. Here and there, however, as the coastal tracts are approached, mountain-tops peer through the ice. But elsewhere no such "nunataks," as they are called, can be seen, and the ice may terminate with a steep wall-like front.

A slow general movement of this enormous *mer de glace* takes place from the centre towards east and west. But the great tongues that protrude from it into the fiords (some of which they entirely fill) flow much more rapidly. One of these—the Humboldt Glacier—is forty-five miles wide where it enters Baffin Bay. Little water is discharged from underneath the wall-like margins of the inland ice; but it is quite otherwise with the large effluent glaciers, from which rivers escape all the year round.

The arctic ice-cap is surpassed in extent by that of the antarctic regions, but so far as the phenomena of chief significance to the geologist are concerned,

the southern ice-sheet is simply an enlarged replica of the inland ice of Greenland. There are certain differences, however. For instance, the antarctic inland ice covers the land almost completely, extending generally into the sea. In Victoria Land, however, the appearances recall those of Greenland—the coastal tracts showing here and there mountainous nunataks, between which great effluent glaciers descend to the sea. In Kaiser Wilhelm Land, on the other hand, no marginal tract is left uncovered, the ice flowing out to sea as one continuous *mer de glace*, and terminating in a vertical wall. There are certain other features presented by the ice-world of the Antarctic (such as the enormous floating "ice-shelf") which are apparently peculiar to those regions, but as their particular significance to the geologist is not very clear, they need not be discussed.

We may now briefly consider the nature of the geological work done by glaciers and ice-sheets. In the case of the ordinary alpine glacier, we are at once impressed by the appearance of the great heaps and parallel ridges of frost-riven debris or *moraines*, as they are called, which line its surface. The origin of that debris is obvious. From its source in a cirque or cirques to its termination, an alpine glacier is overlooked by more or less precipitous heights, from which frost is continually detaching smaller and larger rock-masses, the production of debris being aided by the more or less frequent descent of avalanches. The margins of the glacier become in

THE ALETSCH GLACIER, SWITZERLAND. Showing Crevasses and Superficial Moraines.

Photo: Photochrom Co.

[*To face page* 142.

that way loaded with angular rock-rubble and large blocks and masses of all shapes, the whole forming what are known as *lateral moraines*. The long ridges and banks of debris that extend down the middle of a glacier are termed *medial moraines*, and these, it is hardly necessary to say, result from the union of two or more glaciers. When the glacier reaches its termination, all that superficial rock-rubbish is shot down in front of the ice, where it forms *end-* or *terminal moraines*. (See Plates XVIII-XX.)

As a glacier flows with a differential motion, it is subject to stress and strain, to which it yields by cracking across; so that deep clefts or crevasses come into existence: and the same results are brought about by the irregularities of surface over which the ice makes its way. Wide crevasses often open across a glacier, and when a superficial moraine reaches the brink of such a great gash it is abruptly truncated, and would seem to be finally engulfed, for the surface of the ice on the farther side of the crevasse may be entirely devoid of rock-rubbish. As the glacier flows on its way, however, the engulfed materials begin gradually to reappear at the surface, until by and by the moraine is reconstructed. Its reappearance is due partly to the ablation or superficial melting of the ice, and partly to the curving upwards of the lines or planes of flow.

While superficial moraines are characteristic of alpine glaciers, they never appear upon ice-caps that

are not overlooked by mountains. Now and again an effluent glacier proceeding from a Norwegian ice-cap may have rock-debris showered upon it as it descends its mountain valley, but its course is usually short and the rate of flow comparatively rapid, so that conspicuous lateral moraines cannot be accumulated. The same phenomena characterise the glaciers of Greenland. The great inland-ice from which they come is entirely devoid of superficial debris, but the effluent glaciers when they enter mountain valleys and fiords tend, of course, to become sprinkled with debris along their margins.

There is yet another kind of moraine of which some account must be given. This is known as *bottom-* or *ground-moraine*, from the fact that it occurs underneath glaciers and ice-caps. The moraine in question varies much in character, but consists essentially of boulders and smaller stones of every shape and size, commingled with grit, sand, and clay. There are certain peculiarities that serve at once to distinguish it from superficial morainic matter. While the rock-fragments in the latter are invariably sharply angular and unworn, those in bottom-moraine are blunted, rubbed, and worn, and frequently scratched or striated, smoothed, and even polished. Stones and boulders of this kind, along with grit, sand, and clay, often crowd the basal portion of an alpine glacier, which then resembles a breccia — the ice acting as a binding material. Whence has this rock-rubbish been derived? Did it originally lie on the

THE ALETSCH GLACIER, showing Medial Moraine.

Photo: Photochrom Co.

[*To face page* 144

surface of the glacier, and subsequently find its way through crevasses to the bottom? At first sight that seems a plausible explanation of its origin. Surface-moraines, as we have seen, are often engulfed in crevasses; but the debris thus swallowed up is sooner or later disgorged, and reappears at the surface further down the valley. If crevasses penetrated the whole thickness of a glacier, debris plunging into them might readily reach the rocky bed and become enclosed in the basal portion of the ice. It may be doubted, however, whether crevasses ever extend to the bottom of an alpine glacier, except near the sides where the ice is relatively thin. In the case of moderately sized glaciers the plasticity of ice must at some depth from the surface cause the fractures to heal up, so that unless a crevasse be kept open and deepened by ablation it probably never actually reaches the rock-head. The introduction of superficial moraines in this way to the bottom of a glacier must therefore be exceptional, and cannot wholly explain the origin of ground-moraines. This conclusion is confirmed by the fact that summit-glaciers, which are often so situated that no rock-debris can be showered upon them, nevertheless extrude more or less conspicuous bottom-moraines. And it is the same with ice-sheets, large and small alike—these always disclose moraines of this kind, although the whole surface of the ice above may be totally devoid of rock-debris. In such cases it is self-evident that the ground- or bottom-moraine has been derived

directly from the rocky pavement underneath the ice. The great inland ice of Greenland, it is well known, develops enormous sheets and masses of ground-moraine. The lower strata of that vast *mer de glace*, for a thickness of fifty or seventy feet above its base, often contains layers and irregular sheets of clay, mud, sand, stones, and boulders, all of infraglacial origin, while the upper and much thicker mass of ice shows no such inclusions. When the materials enclosed in the ice below attain a certain mass, the friction caused by their presence impedes the movement of the ice, and deposition or accumulation of bottom-moraine then takes place.

The formation of ground-moraine assures us, therefore, that glaciers are most effective eroding agents. The rock-head over which they advance is ruptured or fractured, ground down, and smoothed. The included stones are not only themselves rubbed and striated, but the surface over which they are dragged becomes similarly modified. Hence, rough excrescences are gradually reduced and rounded off—their surfaces displaying long ruts and grooves where they have been scored by the travelling stones and blocks, and finer striæ and polishing where they have been scratched by hard gritty particles, and rubbed and smoothed by the abrading sand and clay of the bottom-moraine. Such grooving, striation, and polishing appear most conspicuously on the side of prominent or projecting rocks facing the direction of ice-flow. But when the glacier-pavement shows no

PLATE XX

MONTE ROSA AND LYSKAMM.
Photo: Photochrom Co.

[*To face page* 146.

abrupt protuberant rocks, the whole surface may be equally smoothed and striated. Not infrequently, however, the rock-head instead of being thus smoothed is jumbled and broken, and larger and smaller blocks are wrenched out of place. Reefs and slabs of every shape and size thus dislodged are dragged away, while now and again bedded rock-masses are abruptly bent over in the direction of the flow, dislocated, crushed, and shattered.

The rivers that escape from glaciers are invariably turbid. This is another proof of the fact that the grinding of rocks is constantly going on under moving ice. For the mud that renders these rivers turbid is simply fine rock-flour or powder. Many estimates of the amount of this finely reduced rock-matter have been made. It has been calculated, for instance, that the river coming from the Aar glacier carries away daily 280 tons of mud in suspension. The Justedal glacier in Norway, draining an ice-field 820 square miles in extent, discharges in a summer day 1968 tons of sediment, while from the Vatnajökull (Iceland) which drains an ice-field ten times larger than that of the Justedal, the river discharges annually nearly fifteen million tons.

A glacial river strews its valley with enormous quantities of gravel, derived partly from its ground-moraines and partly from its terminal moraines. The gravels are coarsest, as one might expect, in the upper reaches of the valley; lower down the stones are smaller, while sand and eventually mud

become better developed as the distance from the glacier increases, and the valley widens and flattens out. It is worth noting, however, that when high floods occur, considerable deposition of fine sediment may take place over the whole floor of a broad valley. In the case of the Alps, the large lakes act as settling reservoirs, so that most of the rock-flour produced by glacier-grinding is intercepted in close proximity to the mountains. But during the Ice Age, as we shall learn, the sites of all those lakes were occupied by enormous glaciers, the sediments derived from which were swept away from the mountain-region and distributed over widely flooded tracts in the low grounds beyond.

There are many other phenomena connected with glaciers and glacial action to which I have made no reference. Our attention has been confined, in fact, to those which enable us to realise the conditions that obtained in Europe when certain Pleistocene formations were being accumulated. From that limited point of view, the most important conclusion to be drawn from the study of modern glacial action is that frost and glacier-ice are potent geological workers—eroding and denuding, and necessarily producing much waste material in the process. No one has ever doubted the vigorous activity of frost—its effects are too patent in the mountains of temperate latitudes and at all levels in circumpolar regions. But it is otherwise with the action of glaciers. Everyone admits of course that glaciers

carry vast quantities of rock-debris upon their backs. But to what extent do they erode the valleys in which they lie? Unfortunately we cannot see what is going on underneath glaciers and ice-sheets. Only here and there, along the side of a glacier or occasionally within its terminal ice-cave, can we examine its pavement and note how it works. It is therefore just in places where the work of erosion must be at a minimum and deposition at a maximum that direct observations are possible. The snout of a glacier not infrequently may be seen resting upon its terminal moraine, and this has led some observers to infer that glaciers cannot be very effective eroding agents. But if our study of the action of rivers were similarly restricted to their plain-tracks where denudation is at a standstill, what should we know of river-erosion? It is only when we have learned that the alluvia in the plain-track of a river often attain a very great thickness and occupy a most extensive area, that we begin to acquire some notion of the potency of fluviatile erosion. The reflection that all these vast accumulations of sediment—these far stretching plains and deltas—consist of river-alluvia, soon convinces us that, if little or no denudation takes place in the plain-track, great erosion must be effected further up the valley. For it is manifest that deltas only grow at the expense of the drainage-areas from which their materials are derived. If that be self-evident in the case of rivers, it is not less obvious in the case of glaciers and ice-sheets. As a river-valley begins

to flatten out the erosive power of the river gradually decreases, while at the same time deposition of sediment progressively augments. It is the same with glaciers and ice-sheets—as these approach their termination erosion diminishes while accumulation increases. When that termination is reached their direct action of course ceases, and the further transportation of rock-material is given over, as it were, to the rivers that escape from them.

Hitherto we have been considering such glacial action as can be studied at the present day, and have come to the justifiable conclusion that the ability of glaciers and ice-sheets to erode is as well established as that of streams and rivers. But our knowledge of what moving ice can do has been greatly increased by a study of the deserted beds of ancient glaciers. We ourselves live upon the abandoned floor of a mighty ice-sheet which has left indelible evidence of its former presence. The great valleys of the Alps, as we shall learn, were at one time occupied by glaciers, compared with which those of our time are the merest pygmies. Throughout the whole of northern Europe, indeed, and in nearly all the mountains of the central and southern parts of the Continent we meet with similar evidences of intense glacial action. And from an examination of the phenomena thus so abundantly displayed, we gain some notion of what must be taking place underneath existing glaciers and ice-sheets. My next two lectures, therefore, will be devoted to that subject, but I am

tempted on the present occasion to make brief reference to certain particular features of the glaciation which, although only indirectly concerned with my main thesis, are nevertheless of very considerable interest.

One of the most striking features of formerly glaciated lands is the profusion of lakes, both large and small. Consider for a moment the numerous lakes of our own country, of Scandinavia, of Finland, and the Alpine lands, and contrast these regions with lands that have not been glaciated. Were we to colour upon a map of Europe all the countries which have passed through glacial conditions, we should find that outside of the coloured area only a very small number of lakes would be left. Some of these, we should find, occupy the craters of extinct volcanoes. Others are barrier-lakes of one kind or another, caused by the damming-up of streams by landslips or rock-falls. Yet others are due to the action of underground waters, which bring up in solution immense quantities of mineral matter from below, and thus induce sinkings of the surface of less or greater extent. But the multitudinous lakes of glaciated lands cannot owe their origin to any such causes. With very few exceptions they are the result of glacial erosion, and the irregular distribution of glacial and fluvio-glacial formations. Very many occupy hollows excavated by ice, others are ponded behind dams of detritus, while, in the case of a considerable number, the basins are due partly to erosion and partly to accumulation.

The first geologist to call attention to the origin of the lakes so common in glaciated lands, was Sir A. C. Ramsay, who maintained that the rock-basins occupied by them had been ground out by ice. In the case of a glacier, as we have seen, erosion is carried on throughout the whole extent of its bed. Obviously, however, the process of grinding and rupturing must be unequally developed—all parts of the rock-floor cannot be worn down at the same rate. Erosion we should expect to be most vigorously carried on where the ice is thickest, and to be less effective where the ice is thinnest. But the erosion, however great it may be, will not necessarily result in the formation of a rock-basin. For instance, a glacier that descends and terminates on a steeply-inclined surface may be a most effective eroding agent, but it cannot grind out an elongated basin. It is only when it reaches and flows for a longer or shorter distance upon a gently-inclined or relatively flat surface that the conditions become favourable for that kind of formation. After a glacier emerges from the steeper part of its course—from the "torrent-track" of the valley—and deploys upon the less inclined track beyond, the ice, owing to the greatly diminished gradient, heaps up, as it were, and by and by attains its maximum thickness. As it flows on its way, the glacier eventually begins to lose in thickness, and the rate of movement progressively decreases with the gradual attenuation of the ice. Now although we cannot observe what goes on underneath a glacier,

we nevertheless know that erosion does take place, and that it must be greatest where the ice is thickest. We infer, therefore, that in time the glacier must grind out a long trough in the bottom of the valley, the depth and extent of which will be proportionate to the size of the glacier, as also to its duration, and no doubt to the hardness and toughness of the rocks over which it flows. Towards its terminal front erosion ceases and accumulation begins—morainic matter being dumped upon and distributed over the valley-bottom, the surface of which may thus be considerably raised. When the glacier finally disappears, its bed will be marked by the presence of a hollow or depression, due partly to erosion and partly to the accumulation of detritus at its lower end. Needless to say, this basin will be occupied by a lake from which a river will be discharged. In course of time the river may cut its way down through the detritus at the end of the lake and thus lower the level of the latter. When it reaches the solid rock, however, the lowering of the level will not be so readily effected. It is conceivable, indeed, that the lake might be entirely silted up long before the outgoing stream could succeed in draining it.

Many of these glacial lakes attain an astonishing depth, and one is not surprised, therefore, that Ramsay's theory of their origin should have commended itself at first to only a few geologists. It was hard to believe that basins, reaching a depth in some cases of several hundred feet, could possibly

have been slowly excavated by glacial action. But the basins in question are not abrupt and sudden depressions. When we take into consideration their extent, it becomes obvious that they are relatively shallow pans or troughs. The descent from the lower or upper end of such a basin to its deepest part is extremely gradual. Loch Lomond, for instance, is 630 feet deep, but its length is one hundred and seventy-six times greater than its depth. Loch Ness, again, is one hundred and thirty-six times longer than it is deep; and the great lakes of the Alps are all in like case—their depth is only a small fraction of their length. Could the water be removed from any one of these depressions, we should hardly be able to recognise its basin-shape without careful measurement.

The rock-basins of our mountain valleys are not the only hollows which must be attributed to glacial action. In highly glaciated lands like Scotland, we frequently encounter the phenomena known as "crag-and-tail," which are well illustrated by the Castle Rock of this city. Here we have an abrupt rock-mass looking westward, with the long ridge of the High Street sloping gently in the opposite direction. A horseshoe-shaped depression passes round the west base of the Rock, and is prolonged through the Princes Street Gardens on the north side and the Grassmarket on the south side. This hollow is the result of glacial scour at a time when our district was overflowed from west to east by a *mer de glace*

some 2000 or 3000 feet in thickness, which drowned the Castle Rock, Calton Hill, and Arthur Seat, just as a river covers the boulders in its bed. The bottom part of the ice-flow, stemmed by the Castle Rock, was compelled by the current constantly advancing from the west, to exert greater erosive power at the base of the obstruction, and hence in time hollowed out a depression, while behind the obstruction—that is, on the High Street ridge—morainic debris was accumulated. Very much the same action may be observed taking place on the bed of a river immediately in front of a large boulder. The water heaped against the boulder is forced downwards, and thus sweeps out a hollow in front, while the sand and gravel removed by the process tend to come to rest in the rear. The Castle Rock is only a small example of the phenomena of crag-and-tail. In my next lecture I shall point out that deflection-basins on a very much larger scale came into existence elsewhere under the same great *mer de glace*.

Our conception of glacier ice as an eroding agent has thus been greatly extended by a study of the effects produced by the vast ice-flows of the Glacial period. Students of glacial geology have learned much, however, since Ramsay advanced his famous theory. While the glacial excavation of rock-basins is no longer considered improbable, there are many observers who go considerably further in their appreciation of glacial erosion, and maintain that it

alone can account for the great depths attained by the main trunk valleys of the Alps. These, it is well known, have frequently been deepened to a much greater extent than their tributaries. In the long established river-systems of regions which have never been glaciated, we usually find that lateral or tributary valleys gradually widen and flatten out as they approach the main valley. Were such a valley-system to be so far submerged as to allow the sea to occupy the bottom of the main or trunk valley, it is obvious that inlets of less or greater importance would at the same time invade the lower reaches of the lateral valleys. In a highly glaciated mountain area like the Alps, however, the relation of the tributary valleys to a trunk valley is often very different. Take, for instance, the valley of the Rhone between Visp and Martigny. Here we have a broad and deep flat-bottomed valley with more or less precipitous sides—a gigantic trench, in fact—that extends for many miles into the heart of the mountain land. Numerous tributary streams join the Rhone, but only two of these—the Drance and the Visp—occupy valleys that open widely upon the main valley. All the others shoot down through a succession of abrupt, narrow, and profound gorges. Follow one of these upwards to a height of 800 or 1000 feet, and we find ourselves somewhat suddenly in a relatively wide and open valley. Obviously the latter has been truncated or cut across by the great trench of the Rhone. (See Fig. 7.)

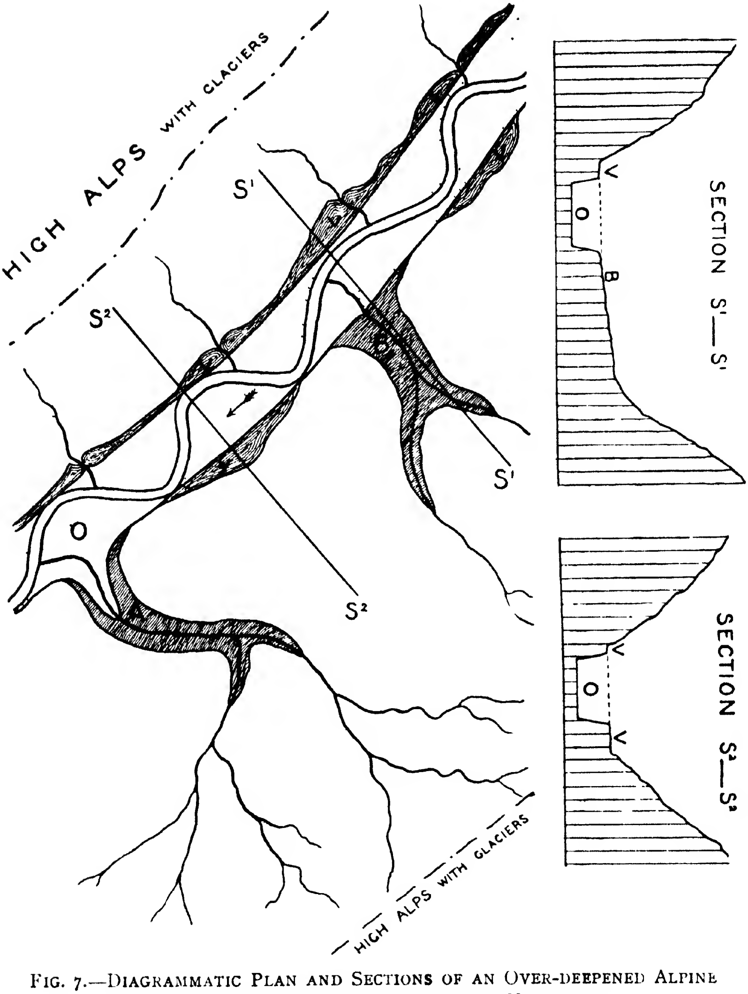


FIG. 7.—DIAGRAMMATIC PLAN AND SECTIONS OF AN OVER-DEEPENED ALPINE TRUNK-VALLEY, WITH ITS TRIBUTARY VALLEYS.

O, Over-deepened valley; V, V, relics of preglacial valley; A, tributary valley draining extensive ice-field; B, tributary valley draining less extensive ice-field, abruptly truncated by main valley.

There is good evidence to show that before glacial times this great disparity of depth between the valley of the Rhone and the high-level valleys from which its tributaries come did not exist. At heights of 800 feet to nearly 1000 feet above the Rhone we encounter terraces and flat embayments in the mountains, which we have no difficulty in recognising as remnants of its old preglacial valley. Not infrequently these terraces can be followed into the high-level tributary valleys, with which indeed they are continuous. In preglacial times, therefore, the river-system of the Rhone was normal—the tributary valleys widening and flattening out as they opened into the main valley. Had nothing occurred to interfere with the ordinary action of the rivers, the relation between the Rhone and its affluents would doubtless have remained normal. But the main valley has been over-deepened to the extent of 800 to 1000 feet or thereabout, and that over-deepening could not have been the work of the Rhone, otherwise the tributary valleys would have been deepened *pari passu*. The trenching of the Rhone valley and the truncation of the valleys that formerly opened upon it in the usual way, must be attributed to glacial action. The main valley being one of the chief lines of drainage was at one time the bed of the most gigantic of the old Swiss glaciers, the thickness of which between the two points Visp and Martigny exceeded 4000 feet. That enormous ice-river, like the great glaciers of Greenland, may have flowed rather rapidly, and if so, must have been a

correspondingly powerful eroding agent. Its numerous tributaries have also scoured their valleys, but owing to their smaller size, and to the fact that they were to some extent dammed back by the enormous Rhone glacier, they could not be equally effective. It was only in such valleys as those of the Visp and the Drance, which drained very extensive ice-fields, that erosion comparable to that of the Rhone valley could be accomplished.

The over-deepening of valleys by glacial action is conspicuous in many other places throughout the Alps—one of the most instructive examples being that of the Lauterbrunnental (see Plate XXI), where the old preglacial valley forms the well-marked lofty terraces of Wengen and Mürren. In the bottom of that valley has been cut the steep-sided U-shaped trench through which the Weisse Lütschine now flows. We have here, in short, a valley within a valley. (See Fig. 8.) That the younger valley has not been excavated by the river, is shown by the fact that the tributary brooks and streams have not yet succeeded in cutting out courses equal in depth to that occupied by the Lütschine. The relation of these tributaries to the river is abnormal. Instead of flowing in hollows that widen and flatten out until they open upon the main valley, many of them (such as the well-known Staubbach) cascade over the precipices that bound the latter, while others descend through narrow and steep gorges in a succession of waterfalls and tumultuous rapids. As the bounding walls of the younger valley rise to a

THE LAUTERBRUNNENTAL, SWITZERLAND.

B, B. Bottom of Preglacial Valley; O, Trench excavated by Glacier-ice.

Photo: Photochrom Co.

[*To face page* 160.

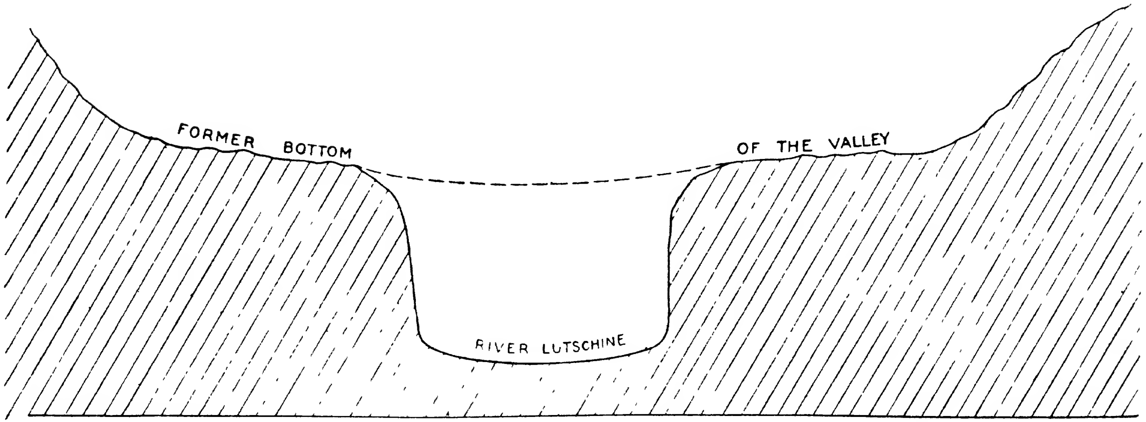


FIG. 8.—DIAGRAMMATIC SECTION ACROSS THE LAUTERBRUNNENTAL.

height of 1000 feet or thereabout, they enable us to realise what is meant by the "over-deepening" of valleys by glacial erosion.

In this account of the work done by glaciers I may seem to have wandered far from my main subject—the geological evidences of the antiquity of man. But, as I hope to show you in subsequent lectures, that is not the case. The history of the Ice Age is to a large extent the history of the Pleistocene period which witnessed the apparition of Palæolithic man in Europe. The excavation of rock-basins, and the over-deepening of great mountain-valleys by hundreds of feet, must of necessity have occupied a very long time. And as these striking modifications of the land were accomplished in whole or in part while man occupied our Continent, they serve to increase our conception of the great antiquity of our race. (See NOTE 9.)

LECTURE VI

THE TESTIMONY OF THE GLACIAL FORMATIONS —*continued*

II.—*Glaciation of Northern Europe*

The Glaciation of Northern Europe. Extent of Scottish Ice and Directions of Ice-flow. Submarine Rock-basins. Southern Termination of Ice-sheet in England. Glacial Excavation on the Floor of the Irish Sea. Rock-rubble in Non-glaciated Areas of England. Scandinavian *Mer de Glace*. Thickness of Ice-sheet that invaded North Germany. Over-deepening of Norwegian Fiords, and Results of Glacial Action in Germany. Contemporaneous Conditions in the Atlantic.

In no part of Europe can the evidence of former ice-action be better studied than in our own country. For this reason I shall describe the general phenomena exhibited by Scotland in some little detail, since they may be taken as typical of all the other glaciated regions of northern Europe.

The most notable of our glacial formations is undoubtedly the till or boulder-clay. This is a more or less gritty clay, usually crowded with stones and blocks of all shapes and sizes. These are not arranged in layers, but confusedly scattered through the clay, in which we look in vain for any trace of

what geologists call stratification. The accumulation, in short, shows no evidence of having been gradually deposited in water and spread out in beds. The stones are subangular, blunted, often smoothed and striated, and resemble in every particular the similar stones and boulders occurring in the bottom-moraines of existing glaciers and ice-sheets. The clay, again, is quite unlike any alluvial deposit. Alluvial clay consists of materials which have been long exposed to the chemical action of rain and superficial water; while the clay of our till is wholly unweathered. Obviously it has been accumulated under conditions which excluded the chemical action that affects rocks of every kind exposed at the surface of the ground. In all these respects it is precisely similar to the clay of a true bottom-moraine. Usually it is very tough and much compressed, often showing lines or planes of shearing, and now and again presenting the appearance of a kind of rude bedding, as if it had been gradually accumulated. But this rude bedding can never be mistaken for that of an aqueous formation.

One may note further that the character of the till is somewhat local. That is to say, a large number of the stones and boulders in any given mass have come no great distance, but belong for the most part to the drainage-area in which the deposit occurs. Closely associated, however, with these stones of more or less local origin we detect others which have travelled much farther. The till of our own district,

for example, consists very largely of materials derived from the Carboniferous strata which extend for many miles to the west of Edinburgh. But among this local material we note not a few stones and boulders that have wandered all the way from the Highlands. Far-travelled erratics are usually the most worn and rounded, while not infrequently fragments which have come but a short distance are quite rough and even sharply angular. In some places, indeed, the bottom part of the till is made up chiefly of large masses and shattered debris of the immediately underlying rocks. In other places, again, the outcrops of the beds below the till have been forcibly bent over or dragged forward in some particular direction.

Water-worn sediments are now and again enclosed in the till. These may consist of mere lines and layers of gravel, sand, and fine clay, or of relatively thick beds. Such inclusions are frequently more or less crumpled and contorted, and curiously involved with the till, and it may be noted that precisely similar inclusions of water-formed beds often accompany the bottom-moraines of the Alps and Arctic lands.

A few words now as to the distribution of the till in Scotland. In the Highlands it is largely confined to wide flat-bottomed valleys and gently-inclined hill-slopes. It is rarely seen in narrow glens, where a few patches, however, may sometimes be found nestling in the rear of prominent rocks that look up the glens. In the Southern Uplands it has a similar distribution, being best developed in the broader

valleys. As the hills of that region, however, have on the whole a softer outline and the valley-slopes are less steeply inclined, the till frequently puts in a strong appearance and covers wide areas. The bottoms of many of the valleys, for example, are continuously paved with it, and when such is the case it has been trenched by streams and rivers, and thus flanks these in bluffs and scaurs. It reaches its greatest development, however, in the Lowlands, where it sometimes attains a thickness of 100 feet or more, and often extends over wide regions. Usually it presents a broadly undulating surface, but in certain districts, as in Teviotdale, Tweeddale, and Nithsdale, it is drawn out, as it were, in a series of parallel banks and hollows, which coincide in direction with that of the broad valleys in which they occur. Followed from the Lowlands to the mountains it tends to become stonier and coarser, often passing into a rough morainic earth.

These facts thus shortly stated suffice to prove that till or boulder-clay is of the nature of a bottom-moraine, and the trend of the ice-flow to which it owes its origin is indicated by the various features I have described. Its true nature, for instance, is shown by the directions in which the included stones and boulders have travelled, by the alignment of the parallel banks or "drumlins," as they are called, and by the phenomena of crag-and-tail. To these proofs of glaciation we add the testimony furnished by the striated and smoothed rock-surfaces of Scotland, such

as are so often exposed when the till has been stripped away. It need only be said these exactly recall the glaciated rocks of the Alps and Greenland. But striæ and *roches moutonnées* are met with abundantly elsewhere than underneath boulder-clay. Wherever bare rock appears at the surface, either in Lowlands, Uplands, or Highlands, it may exhibit traces of glaciation. The striæ no doubt have frequently disappeared, but the rounded and flowing contour characteristic of glacial work often remains. So long a time has elapsed since the Glacial period, however, that frost, rain, and superficial action generally have certainly removed much of the evidence. Nevertheless, that evidence is still so abundant that geologists have no difficulty in making out the direction of ice-flow, not only on the mainland but in the adjacent islands. Rock-striæ and the characteristic glaciated contour have been traced all over the land, from the sea-level up to heights of 3000 and 3500 feet. It would seem, therefore, that the whole of Scotland, with the exception of the tops of our highest mountains, has been smothered in ice.

So copious and detailed are the proofs, that we can even estimate the approximate thickness attained by the Scottish ice-sheet, and determine the slope of its upper surface as it flowed out into the Atlantic. In Wester Ross, for instance, glaciation may be traced up to a height of 3500 feet, while in the Outer Hebrides it does not go higher than 1600 feet. Now the ice-sheet which advanced from Ross in a general

north-west direction filled up the Minch and overflowed the Outer Hebrides. The distance from the Torridon Mountains in Ross to the Cliseam in Harris being fifty-six miles, the slope of the *mer de glace* is readily obtained, and found not to have exceeded thirty-five feet per mile—a gentle inclination. In the central part of the Minch, off the east coast of Harris, the depth of the sea averages 250 feet approximately. Over that region the surface of the ice-sheet must have reached a height of 2550 feet above the present sea-level, and if we add to that the depth of the water (= 250 feet), we get for the *mer de glace* a thickness of 2800 feet. Nearer the coast of the mainland the ice-sheet would, of course, be still thicker, probably more than 3500 feet. (See Note 10.)

It will be readily understood that the configuration of the land—the disposition of high-lying and low-lying areas—must, as a rule, have controlled the direction of the Scottish *mer de glace* as it flowed outwards to the sea. In a general way, therefore, the ice would follow the trend of the principal valleys; but as we trace its spoor down to the east coast we find that, instead of going straight out to sea, it has invariably turned aside. For instance, the ice that occupied Tweeddale flowed in the same general direction as the present river until it approached the sea, when it gradually wheeled round to pursue a south-easterly course. The same change of direction took place in the depression now occupied by the Firth of Forth, the coast-lands as far as St Abbs having been

traversed from west to east, after which the ice-flow swung round to south-east. So again the coastal tracts of the Firth of Tay are striated in the general direction of the Firth, but beyond Dundee the rock-striæ bend away towards north-east, and the same is the case, one may say, along the entire coast-line of Forfar, Kincardine, and Aberdeen. Obviously, the ice-flow descending from the Highlands towards the east coast must have encountered some insuperable obstruction, which compelled it to follow what might at first seem to be an abnormal course. A still more striking example is exhibited by the glacial phenomena of Caithness, along the east coast of which the striæ are directed from south-east to north-west. This shows that the ice streaming from the Highlands into the Moray Firth was deflected from its path, and actually forced to overflow the north-east part of the county. And this invasion from the sea is further proved by the notable fact that the till of Caithness contains many broken and striated sea-shells. Nor is this the only evidence of ice-invasion from the North Sea, for both the Orkney and the Shetland Islands are glaciated from east to west.

In my last lecture I gave some account of the phenomena known as crag-and-tail, and mentioned the fact that in front of the "crag" a hollow frequently appears. The same phenomena, but on a much larger scale, are of common occurrence on the sea-floor off the north-west coast of Scotland. The *mer de glace* coming from the mainland was so thick,

as I have pointed out, that it succeeded in overflowing not a few of the islands of the Inner and Outer Hebrides. Many of these islands, however, attain a considerable height and must have peered like nunataks above the surface of the *mer de glace*. Nor can we doubt that to some extent they obstructed the ice-flow. The latter as it made for the Atlantic followed a north-westerly and westerly direction, and those islands that rose abruptly from the sea-floor to mountainous elevations would necessarily stem the current pressing against them, and thus induce excessive glacial erosion. We are not surprised, therefore, that in front of such steep islands more or less well-marked depressions or basins should occur, some of them reaching a great depth. It is noteworthy that the profoundest depressions of the kind appear off such islands as directly confronted the ice-flows proceeding from the larger sea-lochs. Take, for example, the case of the Island of Arran. That island stood in the path of the ice descending from the Argyllshire Highlands by Loch Fyne and the Firth of Clyde, and the charts show that it is surrounded on north, west, and east by a great horseshoe-shaped depression, the maximum depth of which (444 feet) is attained, where it might have been expected to occur, off the north coast. But the most notable example of the kind is that of the long series of basins in the Minch, extending from south-west to north-east in front of the Outer Hebrides—a direction at approximately right angles

to that of the ice-sheet by which those islands were so largely overwhelmed. It was only the upper strata of the *mer de glace*, however, that could traverse the islands. The latter rise so steeply from the bed of the Minch that the lower strata of the ice could not possibly surmount them, but were deflected to north-east and south-west as an "undertow." Not before the mountain-barrier declined in height into the low grounds in the north of Lewis was that undertow able gradually to invade the island, and to cover it with its bottom-moraine which, like that of Caithness, is charged with crushed and broken sea-shells, taken up doubtless from the floor of the Minch. The deep hollows ranged along the inner margin of the Outer Hebrides are similar in all respects to the depression that so nearly surrounds Arran—they are "deflection-basins," due to glacial erosion, and ranging in depth from 400 feet to 800 feet. "We cannot, of course, tell whether those basins are wholly excavated in rock, or whether they may not owe some of their depth to unequal accumulation of glacial and marine deposits. But their form and disposition, and the whole configuration of the sea-floor so exactly recall the aspect of the ice-worn low grounds of the Outer Hebrides, the rocky coast-lands of north-west Scotland, and similar glaciated regions in other lands, that we can hardly doubt the bottom of the Minch and adjacent areas owes its characteristic features to glaciation—that the deep troughs hugging the shores of the rocky

islands that face the mainland have been ground out by the great *mer de glace* on its passage into the Atlantic."

The glacial phenomena of England tell much the same tale as the boulder-clay and rock-striæ of Scotland; but while Scotland was wholly drowned in its *mer de glace*, large areas in the sister country escaped glaciation. The Yorkshire Moors and a considerable portion of the Pennine Chain, for example, were surrounded but not overwhelmed. The terminal front of the ice-sheet extended south to the valley of the Thames at and near London, whence it seems to have turned away towards north-west into the Midlands, and thereafter swung round by the valleys of the Avon and the Severn to the Bristol Channel.

Although the southern extremity of England escaped invasion by the ice-sheet, it could not fail to experience a severe climate. This is proved by the appearance in many places of great sheets of rock-rubble which have travelled down hill-slopes and overspread wide reaches of low ground. Excellent examples are furnished by the so-called "head" so frequently seen capping the sea-cliffs of Devon and Cornwall. This accumulation recalls the aspect of the "flowing soils and debris" of Arctic lands. It consists of a more or less coarse agglomeration of angular rock fragments of all shapes and sizes set in an earthy matrix. Here and there it has a rudely bedded appearance, but not such as would suggest

arrangement by running water. "Coombe-rock" is the name given to similar sheets of rock-rubble, which extend from the South Downs for some eight miles over the adjacent low grounds. These notable accumulations are made up, as might have been expected, of debris derived from the Downs, and consist, therefore, of "unstratified or obscurely stratified flints, battered but not rolled, and embedded in a matrix of chalky paste and pieces of chalk." Further south the deposits in question pass into an accumulation of flints in a loamy matrix, and eventually change into a brick-earth with scattered angular flints, from which have been obtained teeth of elephant and horse, broken and apparently decayed before they were embedded, and a few Palæolithic implements. Rubble drifts of very much the same character, it may be added, occur in the Channel Islands and the north of France.

But, to return to the ice-sheet, I would remind you of the remarkable deflections of ice-flow which took place along the coastal tracts of the North Sea. The Scottish ice as it issued from Tweeddale gradually turned away towards south-east, and the same deflection has left its marks in the maritime regions of Northumberland and Durham. South of the Yorkshire Moors, however, the direction of ice-flow changed from south-east to south-west throughout all East Anglia. The cause of such notable deflections was the presence of a great Scandinavian *mer de glace* in the basin of the North Sea. The ice streaming out

from Scotland and the north-east of England was sufficiently massive to protect those regions from invasion by the inland-ice of Scandinavia; but it was otherwise in East Anglia, where the foreign *mer de glace* overspread the land with its bottom-moraine, in which fragments of characteristic Scandinavian rocks occur in large numbers.

Ireland, it need hardly be said, was, like Scotland, drowned in a *mer de glace* of its own, sufficiently massive to preserve the island from invasion by any alien ice-flow. The Scottish ice, however, closely approached the north-east coast of Ireland, against which it divided—one branch flowing north-west and the other south-east. A mighty *mer de glace* derived chiefly from Scotland, Ireland, and Wales, but partly also from the mountains of Cumberland and Westmoreland, filled the basin of the Irish Sea. As this great confluent ice-flow passed south it was divided by the high grounds of Wales—one branch streaming south-east across the low grounds of Lancashire and Cheshire, to unite with the Scandinavian ice in the Midlands—the other and larger mass flowing through St George's Channel on its way out to the Atlantic.

The Scottish and Irish ice-flows, uniting on the bed of the North Channel, could not escape mutual constriction, and their erosive action was thus correspondingly increased. The result of this is disclosed by the soundings on the Admiralty Charts, which indicate great depressions on the sea-floor just where we should have expected them to occur. These

basins are quite comparable, in short, to the deep hollows that fringe the inner margin of the Outer Hebrides. Were the British area to be elevated for 600 feet or thereabout, the North Channel and the Irish Sea would be converted into land; but a great elongated lake would appear, extending for some 240 miles from the Scottish Highlands southwards to the region between Wales and Wicklow county in Ireland, with a maximum depth of nearly 600 feet.

Turning now to the Continent, we meet with glacial phenomena the same in kind as those of the British area, but developed on a far grander scale. An ice-sheet covered practically all northern Europe—the centre of dispersion having been the Scandinavian plateau. From that region the ice-flow, as we have learned, filled the North Sea and was confluent with the British *mer de glace.* It overspread the major portion of the Low Countries and north Germany, extending to the foot of the Harz, the Riesengebirge, the Erzgebirge, and the Sudetic ranges. It swept across Finland and occupied all northern and central Russia, broad lobes advancing south to within 200 miles of the Black Sea and the Sea of Azov respectively. In the far north-east it was confluent with the ice that descended from the Urals into the valley of the Pechora. It thus extended from north to south for a distance of at least 1500 miles, and about 2500 miles from west to east.

It is not hard to get some conception of the thickness attained by that enormous ice-sheet.

The average elevation of the inland-ice within the Scandinavian peninsula, from which it radiated, may be taken as 7000 feet above the present sea-level. From this central area of dispersion it flowed south and dropped its erratics and morainic debris upon the northern flanks of the Harz and other mountains of middle Europe, most of which supported snow-fields and glaciers of their own. On the Harz the blocks brought by the ice-sheet from the north occur up to a height of 1350 feet. Now the distance between the area of dispersion and the Harz is 530 miles or thereabout, so that the surface of the *mer de glace* had the very gentle inclination of ten or eleven feet per mile. In southern Jutland, therefore, that surface must have been 2800 feet above the present level of the sea, and if we deduct from this the height of the land, which would be about 300 feet, we obtain a thickness in round numbers of 2500 feet for the ice that passed over Denmark. Again, we get a distance of about 700 miles, when we measure from the site of the Scandinavian ice-shed to the lower slopes of the Riesengebirge, against which the ice-sheet terminated at a height of 1300 feet above sea-level. Along that line, therefore, the surface-slope of the ice could have been little more than eight feet per mile. This would give a thickness of 2900 feet for the sheet in the south of Sweden, and of 1300 feet or thereabout for the ice in the neighbourhood of Berlin.

A *mer de glace* of that extent and thickness could not fail to do much work. Scandinavia and Finland

were severely scoured and abraded—they constituted the area of dominant erosion, while the low-lying plains of Denmark, Holland, Prussia, and central and northern Russia formed the area of dominant accumulation. Throughout this latter region, therefore, the glacial formations attain so great a thickness that the underlying rocks are very seldom exposed. The track of the ice-flow is thus traced chiefly by means of the erratics it carried, but now and again, as in Prussia and Saxony, their testimony is confirmed by that of rock-striæ and *roches moutonnées*. In the Scandinavian peninsula, on the other hand, the path of the ice-sheet is clearly indicated by the strongly glaciated rock-surfaces and the evidence everywhere of extreme erosion. Nowhere, perhaps, is this so apparent as in the great fiords of Norway.

"Norway, as everyone knows, is an ancient plateau, deeply incised and cut up, as it were, into irregular segments. These segments vary much in extent and form—sometimes the surface of the fjeld is flat and undulating, elsewhere it is scarped and worn into irregular groups and masses of variously-shaped mountains and ridges without any determinate arrangement. The orography is everywhere in strong contrast to that of the Alps with their extended parallel chains and longitudinal valleys." Not less strong is the contrast between the fiord-valleys of Norway and the V-shaped valleys of the Alpine Chain —the fiord-valleys being U-shaped and resembling in this respect the over-deepened trunk-valleys of the Alps.

The principal channels of erosion in Norway are deep and trench-like valleys, the tributaries of which are relatively insignificant. The main stream, flowing through a deep mountain valley, eventually enters the sea at the head of a fiord. Below this point, however, few or no side-valleys as a rule break the continuity of the fiord-walls. Numerous tributary waters, some of which are hardly less important than the head-stream, do indeed pour into the fiord, but they have not yet eroded for themselves deep trenches. After winding through the plateau-land in broad and shallow valleys their relatively gentle course is suddenly interrupted, and they at once cascade over the precipitous rock-walls to the sea. The side-valleys that open upon a fiord are thus truncated by the steep mountain-wall as abruptly as if, to use the words of the late Dr Richter, they had been cut across with a knife.

Mountain valleys of the **V**-shaped alpine type are not wanting in the fjeld, but as they are followed inland they soon lose that character and acquire softer features. The valleys of the fjeld lands are for the most part broad and open, many lakes being strung along the courses of the streams. We are here dealing in fact with a plateau lake-land, a region in which glacial erosion has been in excess of accumulation. It is through this gently-undulating, highly ice-worn plateau-land, with its shallow valleys, that the profound chasm-like fiord-valleys have been cut to depths of 3000 to 6500 feet.

A fiord is simply a partially drowned land-valley—the work of erosion of one kind or another. But why should the formation of a main or fiord-valley be so immeasurably in advance of that of its tributaries? Obviously there must have been a time when the process of valley-deepening proceeded more rapidly along the lines of the present fiords and their head-valleys than in the side-valleys which open upon these from the fjelds. Valley-erosion by river-action could not have been carried on equally throughout the land, otherwise a completely developed or normal hydrographic system would have been the result. We cannot doubt that the present valley-system of Norway must have originated in the usual way by river-erosion in ages long prior to the Glacial period. Its present abnormal character, however, cannot be attributed to the action of running water alone, but must be assigned largely to that of the great glaciers of the Ice Age. The fiord-valleys and fiords were the chief lines along which the Scandinavian inland ice made its way. The fjelds were no doubt at the same time scoured and abraded, but the ice attained a much greater thickness, and doubtless flowed most rapidly in the main valleys. The conditions were essentially the same as in the Alps—over-deepening took place in the great trunk-valleys. The fiords with their precipitous rock-walls are comparable to the deep trench of the Rhone between Visp and Martigny, while the truncated side-valleys of the fjelds correspond to the similarly truncated tributary valleys of the

Rhone. The narrow gorges, with their numerous waterfalls and cascades that plunge into the over-deepened valley of the Rhone and other great Alpine valleys, find their counterpart in the abundant fosses, that shoot from the Norwegian fjelds into the fiords. If Swiss glaciers succeeded in deepening their valleys to the extent of 1000 feet or more, we need feel no surprise that the enormous ice-flows descending the trunk-valleys of Norway should have produced similar effects upon even a larger scale. It goes without saying that the excessive erosion—the deepening of a fiord by many hundreds of feet—must have been a most protracted process, extending over a long period of time.

As additional evidence of the powerful action of the great ice-flows of the Glacial period, mention may be made of the extensive contortion, dislocation, and displacement of rocks which now and again took place under the Scandinavian inland ice. The disturbances referred to are on so large a scale that they have often been attributed to subterranean action. Good examples of the phenomena are well exposed in the cliffs of certain islands in the Baltic (Moen and Rügen), where the Chalk, several hundred feet in thickness, has been ruptured, overturned, and displaced so as now and again to overlie and to enclose the bottom-moraine. Again, in Mecklenburg-Schwerin, where the ground is thickly covered with glacial deposits, great masses of Chalk here and there protrude as hills above the surface, just as

if they were *in situ*, but they are now known to be merely huge erratics. On a still larger scale are the rock-displacements seen in Saxony, where the Tertiary Brown Coal formation is often confusedly mixed up with bottom-moraine—wide stretches of strata having been forced out of place so as to appear intercalated in the boulder-clay, as if they formed part of one and the same series, in which position the Tertiary coal-beds have actually been mined. No doubt these are somewhat exceptional cases, for the Chalk and relatively unconsolidated Tertiary strata would yield to the intense pressure exerted by an advancing ice-sheet more readily than denser or harder and more resistant strata. Even the latter, however, have been bent over in the direction of ice-flow, and often fractured and forced out of place.

The glacial deposits covering the peripheral area of maximum accumulation in Denmark, Holland, northern Germany, etc., consist very largely of rock-debris derived from the Scandinavian peninsula and Finland—the areas of maximum erosion. They attain a great thickness, and some attempts have been made to form a rough estimate of the amount of material transferred from north to south. According to Dr Helland, if the abundant erratic materials which at present cover most extensive tracts in Russia and north Germany were to be transferred to Finland and Sweden from which they originally came, they would raise the general surface of those

countries by 255 feet. It ought to be stated, however, that all these materials were not the product of one ice-sheet. As we shall afterwards learn, there have been several glacial invasions of the low grounds of northern Europe, each of which had its share in the formation of the morainic accumulations of those regions.

The terminal front of the great Scandinavian ice-sheet was margined by a zone of less or greater breadth, over which gravel and sand were distributed by water coming from the surface and from underneath the ice. Where the latter abutted upon mountain-slopes, this zone of gravel and sand was of limited width; but where it terminated upon low-lying ground and the water could readily escape, aqueous deposits overspread correspondingly broader areas. Sometimes the gravel and sand are heaped together so as to form multitudinous hills and hillocks, dotted with large erratics, but more usually they appear as undulating or flat sheets often of vast extent. That much loamy material or rock-flour—the result of glacial grinding—was washed out from the ice we can readily believe. Some of this would doubtless come to rest in the abundant temporary lakes of the low grounds, but much must have been carried by the flooded rivers out to sea. To this subject, however, I shall return in my next lecture, after I have discussed the glacial phenomena of the Alpine lands.

Although extensive areas of middle Europe must

have been inundated during the Glacial period, especially in summer, nevertheless much of the relatively low-lying land escaped, and was clothed with an arctic and sub-arctic flora, and roamed over by a tundra fauna. But the conditions of the land at this time will be better understood after we have considered the glacial phenomena of other parts of Europe.

Hitherto I have been referring chiefly to the general aspect of the great inland ice, and discussing the effects it produced upon the land, and we may now turn our attention for a little to the action of ice in the sea. The Scandinavian ice was so thick that it entirely filled up the North Sea, and compelled the British *mer de glace* out of what might have seemed to be its normal course. Many geologists, therefore, have supposed that glacial conditions may have coincided in northern and north-western Europe with a general elevation of the land—that, in a word, the North Sea basin at the beginning of the Ice Age was dry land, and the British Islands formed part of the Continent. But there is really no evidence of any such general uplifting of the land in glacial times. Indeed, such evidence as we have points the other way about—for it proves that the North Sea certainly existed just before East Anglia was invaded by the Scandinavian ice, the approach of which was heralded, so to say, by floating ice, and by the presence in our seas of a well-marked arctic fauna. The notion of a great elevation of the land appears to have been

suggested partly by the exigencies of the now discarded theory, that a general uplift was required to bring about glacial conditions; and partly by the belief that an ice-sheet could not have flowed from Scandinavia to Britain had the North Sea been in existence. But that sea is quite shallow, and could have formed no obstacle to the advance of an ice-sheet several thousand feet thick. It was simply dispossessed, just as in our day the polar seas are dispossessed for miles by the inland ice flowing outwards from the Arctic and Antarctic areas.

It is not difficult to picture to ourselves the conditions that obtained along the borders of the ice-covered tracts of north-west Europe during the Glacial period. Could anyone have approached our Continent from the west at that time he would have encountered, some fifty or sixty miles outside of the British Islands, a great wall of ice—the terminal front of the *mer de glace*, which may well have advanced to what is now the 100-fathoms line. When the increasing depth of the ocean prevented the further advance of the great sheet, the calving of icebergs would begin, and tabular masses of larger and smaller dimensions would forthwith sail away. Probably no Gulf-stream Drift washed the western shores of Europe at that time, the set of ocean currents and dominant winds alike being towards the south. How far south icebergs may have floated we do not know, but they certainly sailed much further away than is now the case, for some of them stranded and left their

erratics on the shores of the Azores, when these islands were slightly depressed below their present level.

That a cold oceanic current passed along the west shores of Europe is further evidenced by certain Pleistocene deposits in Italy, which have yielded a large number of molluscan species that no longer live in the Mediterranean. Amongst these are many North Atlantic forms, and others that are exclusively boreal and even arctic—all of which must, of course, have entered the Mediterranean from the Atlantic. The occurrence of these northern types so far south of their present habitat is quite in keeping with the appearance of marmots and other alpine animals in the low grounds of Italy, and of reindeer and mammoths in southern France and Spain. The Glacial period, in short, was marked by wholesale migrations of floras and faunas from north to south.

LECTURE VII

THE TESTIMONY OF THE GLACIAL FORMATIONS —*continued*

III.—*Glaciation of the Alps, etc.*

Glaciation of the Alps and other Mountains. The Old Glacier of the Rhone. Old Glaciers of the Rhine, the Iller, the Inn, &c. Glacial Phenomena of Upper Engadine. Old Glaciers on South Side of the Alps. Evidence of Glacial Erosion—Lake-basins; Over-deepened Valleys; Great Extent of Ground-moraines, and Fluvio-glacial Deposits. Glaciation of other Mountains in Middle and Southern Europe. Foehn Winds and the Origin of the Loess.

AMONG the most conspicuous evidences of formerly widespread ice-action in the Alpine lands are the large travelled blocks so lavishly scattered everywhere. From an early period these attracted the attention of intelligent travellers, some of whom expressed surprise when they saw that the isolated blocks did not consist of the same kind of rock as that of the mountains on which they lay. The numerous gigantic erratics—some as big as cottages—that strew the flanks of the Jura looking towards the Alps, are often referred to by old writers as specially remarkable. Obviously these had been carried to

where they are now found—but by what mysterious agency? Some, probably all, had come from the Alps, and had therefore travelled many miles. Amongst other vague conjectures it had been suggested that the transporting agent might have been water—that the blocks might have been swept down from the Alps by powerful débâcles or cataclysms. Such views, however, were never considered quite satisfactory and convincing—a more reasonable explanation of the phenomenon had yet to be found. It is interesting to Scotsmen to know that the first to discover the solution of the problem—to divine the true origin of the erratics—was a fellow-countryman, John Playfair, formerly Professor of Natural Philosophy in the University of Edinburgh, and a devoted disciple of James Hutton, one of the founders of the present system of geology. During a visit to Switzerland in 1815, Playfair was much impressed by the great wandered blocks of the Jura. One of these, a mass of granite, he estimated to weigh 2520 tons, and his sagacious reflections are worth quoting, inasmuch as his recognition of the glacial origin of the erratics in question was in point of fact the first step taken to work out the history of the Ice Age. "When we consider," he remarks, "that the present point where the granite is to be found in its native place is at a distance of seventy miles, it will appear no easy matter to assign a conveyance by which this block could have performed such a journey over hills and valleys without consider-

able injury. A current of water, however powerful, could never have carried it up an acclivity, but would have deposited it in the first valley it came to, and would in a much less distance have rounded its angles, and given to it the shape so characteristic of stones subjected to the action of water. A glacier which fills up valleys in its course, and which conveys the rocks on its surface free from attrition, is the only agent we now see capable of transporting them to such a distance, without destroying that sharpness of the angles so distinctive of these masses."

Some fifteen years, however, were to elapse before the study of the glacial formations of the Alps began to be seriously attacked by scientific men. It is chiefly to Charpentier and L. Agassiz that we owe the first clear outline of the several phenomena which unite to prove beyond any question that the Alpine glaciers were formerly much more extensive. These early observers indeed may be truly said to have laid the foundations of glacial geology. During the many years that have passed since the results of their investigations were given to the world, hosts of geologists from every country have visited the Alpine lands and increased our knowledge of their glaciation. But the next most notable advance was made when Morlot in 1854 and Heer in 1858 discovered that there had been more than one great extension of the glaciers. These two investigators were the earliest to recognise the existence of certain accumulations which have come to be known as

"interglacial" formations. Still later it was reserved for a Scotsman, Andrew Crombie Ramsay, to demonstrate that the great Alpine lakes occupy basins of glacial erosion. His views were for years pertinaciously contested, but many of his opponents, who thought that he had greatly exaggerated glacial erosion, are to-day constrained to admit that glaciers are much more effective agents of erosion than Ramsay himself had suspected. In short, it is now maintained, as we have learned, that many Alpine valleys have been throughout deepened by glacial action, and that the present rock-basins, profound and capacious as they may be, are yet of subordinate importance. They are, in short, relatively shallow depressions hollowed out in the bottoms of valleys, which in many cases had been already over-deepened by glacial scour and excavation.

Many other questions connected with the glacial history of the Alpine lands have interested geologists since the appearance of Ramsay's paper, *On the Glacial Origin of Certain Lakes in Switzerland;* but important as these are, it must be admitted that by the work of the earlier observers the fundamental conclusions of glacial geology had already been established. Shortly stated, these conclusions are as follows: (*a*) the former greater extension of the glaciers; (*b*) the periodical return of such extensive glaciation; and (*c*) the effective action of glacier-ice as a modifier of the earth's surface. Nearly thirty years ago Dr Penck, in his well-known work on the

glaciation of the German Alps, recognised that these conclusions summed up the chief results of glacial research hitherto obtained, and in his and Professor Brückner's recent great work—*Die Alpen im Eiszeitalter*—the same opinion is expressed with regard to the present position of glacial geology. It is needless to say, however, that the problems considered by the older glacialists have since their time been looked at from other points of view, and treated in a different manner, while many subsidiary problems of much interest and importance have been discussed. Only those who are conversant with the literature of the science can realise the great advances made within the past thirty or forty years. By the following of new lines of research and the employment of improved methods of investigation, our knowledge of the history of the Ice Age of Europe has been in a manner revolutionised. And no researches of the kind have been more fruitful in results than those pursued in the Alpine lands.

The Alpine glaciers of the Ice Age attained gigantic proportions as compared with their puny successors of to-day, but it must not be supposed that the mountain-land was ever so continuously covered with ice as is the case with Greenland. The ancient glaciers did not, like the vast Arctic glaciers, draw their supplies from one uninterrupted snowfield, but each was fed from its own particular névé-basin. Nevertheless neighbouring glaciers were in many cases not so independent, so sharply separated from

each other as in our day. Not infrequently they coalesced across what are now dividing watersheds. This was especially the case on the northern slopes of the chain, as in Switzerland, North Tyrol, and Upper Bavaria. In those regions the glaciers reached the low forelands, where they united to form a continuous ice-sheet. It was otherwise, however, with the glaciers that descended from the higher Alps towards the east and south-west. These were clearly separated from each other, and did not coalesce even upon the low grounds; many indeed dropped their terminal moraines well within their mountain valleys. The same to some extent was the case with the ice-flows that drained the southern flanks of the chain. Several of these, however, deployed upon the forelands—the glaciers that occupied the sites of the great lakes Maggiore, Lugano, and Como uniting outside of the mountain valleys to form a continuous ice-covering. It would appear, therefore, that the middle section of the Alps, between Switzerland and Upper Bavaria on the one hand, and the region of the Italian lakes on the other, was the area of maximum glaciation. The elevated central part of that area was covered with continuous ice, from which glaciers flowed north, while others trended south. It is worthy of note, however, that the ice-shed separating those two sets of streams nowhere coincided with, but lay north of the watershed. The same fact has been observed in connection with the glaciation of the Scandinavian peninsula and the Scottish Highlands—in neither of those regions

did the ice-shed of glacial times coincide with the watershed.

In general terms it may be said that the glaciers of the Ice Age were simply exaggerations of their present successors. The latter are fed from the same névé-basins as those from which the glaciers of the Ice Age drew their supplies. It would appear, moreover, that these basins were not, save in the central part of the chain, more deeply filled in Pleistocene times than they are now. According to Professor Penck, the Alps above the existing snow-line must have much the same appearance as they had in the Glacial period. If this be the case, then it would seem that the former vast development of glaciation was due, not so much to increased precipitation of snow, as to a lower rate of ablation or melting. In other words, extreme glacial conditions were the immediate result of a general lowering of the temperature. It is further notable that the precipitation of glacial times bore a close relation to that of the present. The areas of maximum and minimum precipitation during the Ice Age and in our own day are the same—the existing snow-line running approximately parallel to that of the Glacial period, but at an average elevation of 1200 metres above it.

The general facies of the organic remains, met with here and there in the moraines and fluvio-glacial gravels of the period, are quite in keeping with these conditions. On the north side of the Alps the great confluent glaciers terminated in a dreary tundra-like

region, lying some 400 to 600 metres below the depressed snow-line. From the ice-front escaped numerous glacial streams, which distributed broad sheets of shingle and gravel over the low forelands. During summer these gravel-flats would necessarily be traversed by a network of water-courses which in winter-time would be mostly dried up. The foreland of the Alps would thus seem to have resembled the tracts extending outwards from the Vatnajökull in Iceland. It was, in short, a desolate region, but sufficiently clothed with vegetation to tempt thither the mammoth, the woolly rhinoceros, and the reindeer. The conditions on the south side of the Alps were, according to Penck, less forbidding. There the snow-line was higher, and forests extended up to a height of 800 to 1000 metres, so that many of the glaciers must have invaded tree-covered areas; and it is even quite likely that trees may here and there have grown upon the moraine-covered glaciers themselves, just as is the case to-day in Alaska and the Himalaya.

The gravel-flats spreading out in front of the southern ice-flows were not so sterile as those on the opposite side of the mountains. In certain places, not liable to be flooded by the glacial waters, a somewhat rich molluscan fauna flourished. Forests, however, did not extend everywhere along the foot of the mountains; on the contrary, wide stretches of marsh and peat-bog covered considerable tracts, the pools in which nourished alpine diatoms. The great

mammals that roamed the tundras on the north side of the chain appear not to have frequented the forest-lands of the south. The teeth of mammoth, which are not uncommon fossils in the northern gravel-beds, occur very rarely in the south, one specimen alone having been obtained, while remains of the reindeer have been met with only at Mentone on the west, and in Carinthia on the east side of the Alps. Of the woolly rhinoceros no trace has been found. It is further notable that the arctic element, so conspicuous in the glacial fauna of the north, is not present in the south, where the fauna is characteristically alpine—chamois, ibex, alpine hare, and marmot having ranged far south in the peninsula. According to Professor Penck, therefore, the southern foreland of the Alps must have resembled the south coastlands of Alaska rather than the drearier wastes of Iceland. Towards the east and south-west extremities of the chain, the larger glaciers must likewise have descended into forest-clad land. Many of the smaller ice-flows of those regions, however, were confined to the upper reaches of the mountain valleys. The general aspect of middle Scandinavia probably reproduces, not inaptly, the conditions that characterised the two ends of the Alpine chain during glacial times—the summits of the south-west Alps appearing then not unlike the present snowy heights in the interior of New Zealand.

I have said that the Pleistocene glaciers of the Alps must have resembled their puny representatives

in almost every respect except size; and to bring this all-essential difference clearly before you, I may contrast certain existing Alpine glaciers with their Pleistocene predecessors. The present glacier of the Rhone, as everybody knows, is one of the smaller glaciers of the Alps. At its source, some 10,200 feet above the sea, it is surrounded by peaks and ridges that range in height from 500 feet to about 2000 feet higher. After a course of less than six miles it terminates at a height of some 5700 feet. Now contrast this with the ancient glacier. At its source the latter reached on the flanks of the Schneestock a height of 11,600 feet, or 1400 feet above the surface of the existing glacier. At Visp, sixteen miles further down the valley, the upper limits of glaciation occur at a height of over 5500 feet above the river. Opposite Leuk (twenty-five miles below Visp) the flanks of the Illhorn are ice-worn up to more than 4900 feet. Again, at Martigny (thirty-five miles below Visp), glaciation can be traced on l'Arpillé to a height of 5300 feet above the bottom of the great valley. After leaving its relatively narrow course, the ancient glacier spread itself over the site of the Lake of Geneva, and all the adjacent low grounds, and abutted upon the southern flanks of the Jura, only the higher ridges of which rose above the surface of this great *mer de glace*. On the slopes of Le Chasseron above Yverdon, at the head of Lake Neuchâtel, the upper limits of glaciation occur at a height of 4300 feet, or 3100 feet above the

surface of the Lake of Geneva. "The higher ridges of the Jura overlooking the Swiss Lowlands seem, in short, to have formed islets or nunataks in the broad sea of ice which overflowed through passes in the mountains, reaching Ornans, some thirty miles north-east of the Le Chasseron, and Salins, a similar distance in a westerly direction."

It is hardly necessary to say that this overflow through the passes of the Jura was from the upper portion of the great glacier, the lower strata of ice could not mount the rocky barrier, but were deflected by it to right and left—one branch of the sheet flowing away towards the north, and the other in the opposite direction. As the latter "passed out of Switzerland, it was joined by the glacier of the Arve and other ice-streams coming from the mountains of Savoy, and flowed at first due south, being prevented following a westerly course by the opposing mass of the Grand Colombier. On the flanks of this mountain, opposite Culoz, thirty miles below Geneva, glaciation goes up to a height of 9300 feet. Rounding the Grand Colombier, the united ice-streams of Rhone and Savoy, now joined by the glaciers of Dauphiny, fanned out upon the low grounds of France—showing a frontage that extended from Bourg, Trévoux, and Lyons to Vienne, and thence by Beaurepaire to Vinay in the valley of the Isère, a distance of more than 100 miles. It is interesting to note that between Culoz and Grenoble, all the hills under a height of 3900 feet are rounded

and ice-worn and sprinkled with bottom-moraine. After crossing the secondary chain of the Grand Chartreuse and the Dent du Chat, the old *mer de glace* rapidly lowered its surface as it deployed upon the plains of Dauphiny and the Dombes."

The heights attained by glaciation enable us to form some conception of the inclination of that surface from the source of the glacier in the névé-fields under the Schneestock to its termination in the low grounds of France. From its source to Oberwald, a distance of nine miles, the descent was steep, for the bed of the valley between those two points has an average fall of probably not less than 700 feet per mile. The slope of the surface of the old glacier in this steep part of its course was therefore some 300 feet per mile. From Oberwald to Leuk (thirty-nine miles) the surface slope declined to seventy-five feet per mile. From Leuk down to Martigny the inclination of the surface was not quite two feet. This slight fall points to the gorging of the valley by such glaciers as those of the Aletsch and other tributaries. From Martigny to the Lake of Geneva the surface-slope increased, but over the lowlands of Switzerland the surface must have approached horizontality. The inclination, however, again increased to forty-two feet per mile as the ice crossed the secondary chain to fan out upon the low ground beyond. The total length of the glacier being 245 miles, its surface-inclination from source to termination was rather more than forty-three feet per mile. But from the head of the Lake of Geneva to

Lyons—*i.e.*, the lower course of the glacier—the fall of surface hardly exceeded thirty-five feet per mile.

The north branch of the Rhone glacier need not be followed in detail. I may just note that, like the southern branch, it sent longer and shorter ice-streams through the chain of the Jura. Flowing away to north-east it was joined successively by the glaciers of the Aar, the Reuss, and the Linth, and thereafter this united ice-flow became confluent with the great glacier of the Rhine. How far down the valley of the Rhine the massive glacier extended is somewhat uncertain. It appears to have been confluent with the glaciers of the Black Forest, but the great valley is so deeply covered with fluvio-glacial and alluvial accumulations that we cannot say where the ice-stream actually terminated. We know, however, that the enormous Rhine glacier occupied the site of Lake Constance, and extended north into the valley of the Danube for nearly forty miles beyond the northern shores of the lake. Immediately to its right it seems to have coalesced with the glacier of the Iller, the terminal moraines of which occur about eighteen miles north of Kempton, and therefore well out upon the foreland. Next, passing towards north-east, we encounter the terminal moraines of the confluent glaciers of the Lech and the Isar—the moraines of the latter extending some nine miles north of the Ammer See. The Isar glacier coalesced on its right with the glaciers of the Inn and the Salzach. Thus at the climax of the Glacial period the northern

forelands of the Alps were covered by a continuous *mer de glace* that extended from the valley of the Rhine through Baden, Hohenzollern, Würtemberg, Swabia, and Upper Bavaria to the valley of the Salzach—a distance, not following the sinuosities of the ice-front, of some 250 miles.

Before leaving these glaciers I may take special note of one—that of the Inn—on account of the apparently abnormal course it followed in the upper reaches of its valley. The river Inn rises in the Silsersee at the head of Upper Engadine, whence it holds a general north-easterly course until it leaves the mountains. The Engadine, as the upper portion of the valley is called, is broad and trench-like, resembling in that respect the similar longitudinal valley of the Rhone above the Lake of Geneva. The most notable feature of the Inn valley is the remarkable width it attains at its very head. Near Maloja it is as broad as for many miles further down—the head is reached not in a cirque or deep mountain gorge but in a broad lake. Immediately above the upper end of this lake we cross a narrow ridge of no great height, and find ourselves on the verge of a precipice that sinks abruptly into the deep Val Bregaglia. Obviously the Engadine and the Val Bregaglia are different portions of one and the same great longitudinal hollow—the former trending north-east into Tyrol, and the latter south-west towards Chiavenna and Lake Como. The divide between the two valleys is far too narrow and too low to have

formed a gathering ground for snow to feed the vast glacier which we know occupied the Inn valley. Yet the evidences of glaciation are conspicuous throughout the whole extent of that long hollow from its source to its termination. Ground-moraine in many places paves the floor of the valley, striated rocks, and *roches moutonnées* appear again and again, while the mountain slopes on either side are severely glaciated up to a height of 2000 feet above the river. The line separating the glaciated rocks below from the rough non-glaciated rocks above is particularly well-marked—side moraines and erratics occurring at and below that line.

The descent of the valley from the Maloja is quite gentle. To Celerina or Samaden (opposite the mouth of the Pontresina valley), a distance of ten miles, the fall is not more than 230 feet, or twenty-three feet per mile, and most of that fall takes place between St Moritz and Celerina—the descent from Maloja to Campfer (seven miles) not exceeding three feet per mile. The glacier of the Inn, having no independent névé-field of its own, must have been fed entirely by its numerous tributaries. Only a brief glance at a good map of the district suffices to show that this must have been the case, and the fact becomes very evident when we trace the direction of ice-flow. The trend of rock striæ and *roches moutonnées*, and the "carry" of erratics, demonstrate that the glacier, instead of flowing *down*, flowed *up* the valley from Celerina to Maloja. The cause of

this apparent anomaly is not far to seek. The Pontresina valley opening upon the valley of the Inn from the south-east was gorged with ice, supplied chiefly by the Morteratsch and Roseg glaciers. That ice flowing into the Inn valley, nearly at right angles to its direction, was deflected to right and left. The left branch was thus compelled to make its way for ten miles up the valley, being joined by several lateral tributaries before it reached Maloja, after which the united ice-flows poured into the Val Bregaglia, and subsequently joined the massive glacier that flowed by Como and Lecco into the low grounds of Italy. The right branch, on the other hand, followed a normal course down the Inn valley through Tyrol, and eventually fanned out upon the foreland in Bavaria, with a frontage of nearly seventy miles—the point of the great ice-lobe extending forty-five miles beyond the mouth of the mountain valley.

The glaciers that descended the south side of the Alps did not, for obvious reasons, attain the extraordinary dimensions of such ice-flows as those of the Rhone, the Rhine, and the Inn. The latter drained a much greater extent of mountainous land, while the climatic conditions in the north and south differed then as they differ now. The snow- and névé-lines of the present descend to a lower level on the north than on the south side of the Alps, and the same was the case in glacial times. Yet the glaciers that invaded the valley of the Po were of considerable size and not less important than some

of their northern contemporaries. The ice-flow that occupied the valley of the Dora Riparia—the deep and broad depression traversed by the Mont Cenis railway—deployed upon the plains of Lombardy, and piled up its large terminal moraines at Rivoli, eight miles west of Turin. This, although one of the smaller Italian glaciers, had an ice-front some six miles in extent. The glacier of the great valley of Aosta, draining a far more extensive and loftier tract of mountains, necessarily attained much more notable dimensions, for it flowed for twenty miles beyond the mouth of the mountain valley, and terminated with an ice-front nearly forty miles in extent. Its end moraines at Ivrea are correspondingly enormous, constituting as they do a ridge of hills that rise several hundred feet above the level of the plains. Coming further east we next encounter the moraines of a grand *mer de glace* formed by the union of several important glaciers, the beds of which are indicated by the basins of Lakes Orta, Maggiore, Lugano, Como, and Lecco. These confluent lobes of ice had a width of not less than sixty miles. The glacier of Lake Iseo flowed out upon the low grounds for seven miles beyond the mouth of its mountain valley; while the larger glacier of Lake Garda advanced for some nine miles beyond the termination of the lake — the ice-lobe measuring over seventeen miles in width between Castiglione and Sommacampagna. Further east the glaciers were not so large. Several, however,

deployed upon the low grounds, as, for instance, those of the Brenta-Piave and the Tagliamento.

It is difficult to realise the amount of work done by the ancient glaciers of the Alps. The excavation of the rock-basins now occupied by lakes must have occupied a very long time, no matter how relatively rapid the process may have been. But the formation of these basins, extensive and deep as many of them are, hardly impresses one so much as the general over-deepening of the main valleys. When we think of those valleys being deepened throughout a large part of their course for several hundred feet, we cease to be surprised at the great extent and thickness attained by bottom-moraines in the low-lying parts of the Alpine lands. Naturally these moraines are seldom thick in the areas of dominant erosion, save here and there where the configuration of the surface and the conditions of ice-flow favoured their accumulation. It is upon the low grounds that spread out from the foot of the mountains that bottom-moraine reaches its greatest development. "All the wide tract between the Alps and the Jura, for example, is more or less thickly covered with it. It likewise extends in broad sheets along the northern front of the Alps, overspreading very considerable areas in south Germany. Similarly it cloaks large parts of the low grounds of Savoy and Dauphiny, and the middle valley of the Rhone in France, while round the lower ends of the great lakes of Italy it puts in a prominent appearance." In the case of the existing

puny glaciers some portion of their subglacial detritus or bottom-moraine may possibly be derived from above, but such could hardly have been the case with the gigantic ice-flows of the Glacial period. It is inconceivable that during the climax of glaciation any notable amount of rock-rubbish derived from superficial sources could have made its way down through the thick ice-masses, and entered into the formation of their bottom-moraines. The latter, in a word, are the direct product of glacial erosion.

It would be a great mistake, however, to suppose that these bottom-moraines are the only products of glacial erosion. Immense quantities of material must have been swept out from underneath the ancient glaciers by the large rivers escaping from them. The enormously thick and wide-spread sheets of gravel that cover so much of the forelands on the north side of the Alps consist to a large extent of subglacial detritus, water-worn and re-arranged. And the same is the case, but in a lesser degree, with the deep gravelly deposits that stretch from the foot of the Alps into the plains of the Po. Here, however, superficial morainic matter was dumped in front of the ancient glaciers to a much greater extent than was the case with the terminal moraines on the other side of the mountains, and consequently a considerable portion of the old river-gravels of the Po valley may well consist of materials which originally travelled down the mountain valleys as surface moraines.

The subglacial rivers swept along not only much shingle, gravel, and sand, but vast quantities of fine materials which could not come to rest in the immediate neighbourhood of the mountains. What became of that fine muddy sediment? We cannot doubt that most of it discharged from the south side of the mountains would be transported seawards. But the conditions were very different in the low grounds that spread northwards from the Alps, which were traversed then as now by rivers coming from a glaciated area. We can well believe that during the summers of the Ice Age the swollen muddy rivers would inundate immense areas of low-lying land. The valleys of the Rhine and the Danube, for instance, must have been flooded to an extent impossible under existing conditions. The slack waters and temporary flood-lakes, formed in that way, would then become settling reservoirs, in which fine sediments would accumulate from year to year. Such is believed by many geologists to be the origin of the materials which I described in a former lecture as *loess*. The loess, in short, consists in large measure at least of flood-loam which, as already explained, was at a later stage blown about and redistributed by the wind.

From this very rapid summary of the evidence derived from a study of the great lake-basins, the over-deepened valleys, the vast accumulations of bottom-moraine, of fluvio-glacial gravel, and flood-loams, we cannot but conclude that a Glacial epoch must have been one of prolonged duration.

Lest it should be supposed that I have exaggerated the extent of the snow-fields and glaciers of the Alps during Pleistocene times, I shall ask you to consider the conditions that obtained contemporaneously in other parts of middle and southern Europe. I have mentioned the fact that the ranges of the Jura were traversed in several places by an overflow from the great *mer de glace* of the Rhone, underneath which the low grounds of Switzerland were drowned. But the Jura supported snow-fields and had large independent glaciers of its own. The same was the case with the Vosges and the Black Forest, the moraines of which have long been known. In like manner the Harz and all the mountains of middle Germany, together with the Carpathians, nourished glaciers, some of which attained a considerable size. It is needless to say that the Ural Mountains also supported independent snow-fields and glaciers, more especially towards the northern end of the range.

More notable, however, are the glacial phenomena occurring in regions further south. The Balkans and other hilly tracts in south-east Europe exhibit abundant evidence of former snow-fields and glaciers, and it may be added that similar traces occur again and again in the mountainous regions of Asia Minor. Ice-worn rocks and moraines testify likewise to the existence during Pleistocene times of glaciers in the Apuan Alps, and more notable still in the less elevated Apennines—regions which in our day are

devoid of perennial snow-fields and glaciers. So, again, the mountain valleys of Corsica have their ancient moraines, while the sierras of central and southern Spain bear like witness to the former presence of considerable glaciers. Evidence to the same effect is forthcoming from the Serra da Estrella of Portugal, and from the Asturian Mountains and the Pyrenees. The last-named mountains still carry snow-fields and glaciers, but these occur only in the loftier parts of the chain, the glaciers forming mere patches, as it were, on the flanks of the highest mountains. The largest of these glaciers, after a course of two miles, terminates at a height of 7200 feet above the sea. "Viewed from the south the crest of the chain appears bald and naked, and even the northern slopes of the mountains throughout long stretches show, in the height of summer, no snowy covering. Only here and there are the highest ridges and peaks flecked with snow and spotted with small glacier-patches. During the Glacial period, however, these mountains presented a very different appearance, great glaciers flowing north and south from the dominant crest." The largest of these was the glacier of the Garonne which, coming from a height of 8400 feet, flowed north for a distance of forty-five miles to near Montréjean, where its moraines occur at 1500 feet above sea-level. In its lower reaches this glacier was over 2600 feet thick, and formed a broad *mer de glace*, from which branches overflowed through passes into adjacent valleys.

Another large glacier was that of the Ariège, which had a course of thirty-eight miles. After its confluence with the glacier of Vic-Dessos, the united ice-flow exceeded 1300 feet in thickness. The last of these ancient French glaciers that need be mentioned is that of Argelès, which, having its source at a height of 9000 feet, flowed for a distance of thirty-four miles and terminated at Adé, some 1300 feet above the sea. The greatest thickness it attained was 3000 feet.

The glaciers on the Spanish side of the Pyrenees were less extensively developed, thus presenting the same contrast that obtained in the Alps between the glaciers that flowed down the northern and southern slopes of that great mountain-land. And the causes of the contrast were doubtless the same in both cases—the southern exposure and more rapid descent into the low grounds of Italy and Spain respectively. The largest glacier of the southern Pyrenees—that of the Gallego valley—was thirty-eight miles in length, but the others were neither so numerous nor so important as those on the French side of the mountains. According to Dr Penck, the Spanish glaciers had a mean length of under twenty-five miles, and terminated at the level of 2600 feet above the sea; while the average length of the French glaciers was over thirty-eight miles—their terminal fronts occurring at a height of 1600 feet above the sea. During the Ice Age the snow-line of the Pyrenees appears to have been depressed some 3600 feet below its present level,

and, just as in our day, it gradually rose from west to east.

In the more elevated tracts of southern and central France, now all below the snow-line, traces of former glaciation are often met with. In the Cevennes and the plateaus of Aubrac and Auvergne old moraines are frequently encountered. The evidence of former glacial action is especially well displayed in the high plateau region of Auvergne, so famous for its numerous and often well-preserved volcanic cones, of which the most important are Puy de Dôme (4806 feet), Mont Dore (6188 feet), and Cantal (6093 feet). From each of these volcanic mountains considerable glaciers descended and spread far out upon the surrounding plateau. It is interesting to note that Acheulian implements are frequently met with lying on the surface of the morainic accumulations laid down by these ancient ice-flows.

Further north in France evidences of former glaciation occur at considerably lower levels. In the mountains of Beaujolais and Lyonnais, for example, several glaciers of considerable size have left indisputable traces behind them. The largest of these had its source in the mountain-mass of Saint-Rigaud, some 3300 feet in height. Snow-fields, however, existed in the same region at levels not exceeding 2600 feet, from which glaciers descended. A little further south rises the isolated mountain-group of Mont Pilat (4900 feet), in the valleys opening out from which moraines of important ice-flows may be

seen. More notable still are the relics of glaciation met with in the plateau of Morvan, which reaches an extreme height of 2960 feet. Large erratics and morainic debris occur plentifully round the Morvan, showing that glaciers have streamed outwards in many directions from the dominant heights. Great sheets of fluvio-glacial gravel spread down all the valleys of that region and extend even into the Paris basin, where erratics derived from the Morvan have long been recognised.

In many other parts of middle and southern Europe where no true moraines may occur, we are nevertheless not without other evidence of cold climatic conditions. Almost everywhere we meet with heaps and sheets of rock-debris of essentially the same character and origin as the limestone-breccias of Gibraltar and the "head" of southern England. They are of course most notable in hilly regions, as in the Vosges, the Black Forest, the Swabian and Franconian Jura, the Carpathians, the Balkans, the Apennines, the Sierras of Spain and Portugal, the high-lying parts of southern and central France, etc. The rubble-heaps referred to not only cloak the hill-slopes, but extend down the valleys or spread outwards for considerable distances over adjacent low-lying tracts. They have everywhere the same character:—they consist of local materials, have been formed under conditions very different from the present, and are no longer accreting but gradually wasting away.

The evidence now adduced may suffice to convince you that the climate of Europe during a glacial period must have been very cold. Before concluding this rapid review of the evidence, let me once more refer to the wide-spread loamy deposits known as loess, in which remains of the tundra and steppe faunas and relics of Palæolithic man frequently appear. I described these loamy deposits as having been rearranged by the action of wind, but nothing was said as to the cause of the dry climatic conditions of the steppe period, or of the source of the materials which the wind distributed so lavishly over southern Russia. Some have supposed that when an ice-sheet covered northern and north-western Europe, it must have acted as a powerful condenser upon the moist winds from the Atlantic. Precipitation, it has been inferred, would take place before the clouds could reach central Europe, and the climate there would consequently be very dry. France could not be much affected in that way, but the dryness would steadily increase as the heart of the Continent was approached. We have no reason to believe, however, that the prevalent winds in glacial times came from the west, and even if they had it is not easy to see how or whence they could have obtained sufficient materials for the formation of the loess. During the climax of glacial times the inland ice of Scandinavia flowed south to the foot of the mountains of middle Germany and thus covered much of the area presently occupied by loess. We must remember, moreover,

that most extensive regions throughout middle Europe must have been inundated by the waters escaping from that northern ice-sheet and from the great glaciers of the Alps and other mountains. Doubtless much loam would then be deposited in the slack waters and temporary lakes of the time. It could only be during winter, however, when these waters were much reduced in extent, that loamy materials could be exposed at the surface over any considerable areas. Moreover, when we keep in view the great extent and thickness attained by the loess throughout central and especially south-east Europe, it is impossible to believe that its materials could have been caught up by the wind from the relatively limited tracts left dry in the winter of a glacial period. In southern Russia alone the loess extends from 55° 55′ N. lat. to the Black Sea, and reaches even as far south as the Caucasus. The late Dr Croll was of opinion that the prevalent winds during a glacial period would not be westerly as they are at present, but northerly and north-easterly. He thought they would be exceedingly powerful, in consequence of the great difference in temperature between high latitudes and the equator. More recently M. Tutkoffski has come to a somewhat similar conclusion. He believes that over the inland ice an enormous anticyclonic system existed which induced constant centrifugal winds. These winds would die away in the circumjacent regions, but far beyond the limits of the ice-sheet. They would thus partake of the

character of foehns, having a temperature elevated in proportion to the descent from the high central part of the ice-sheet towards its much lower periphery. They would also be very dry winds. Such conditions are to some extent realised at present in polar regions, being most pronounced where glaciation is most extensive, as in the north of Greenland.

The geological action of the foehns of Pleistocene times could not come into play while the ice-sheet was advancing or had reached its limits. Extensive areas in front of the *mer de glace* would at that time be inundated, while the regions beyond would be protected from the action of wind by the compact covering afforded by the vegetation of the tundras. In western Europe, therefore, great sheets of sand and gravel, liable to frequent inundation, would form a broad marginal zone in front of the ice-sheet; in middle Europe the waters of ablation, dammed up to a large extent by the mountains of Germany, would have more difficulty in making their escape; but in eastern Europe no such barriers existed, the wide valleys of the Dnieper, the Don, and the Volga opening a way directly to the south. A broad zone in southern Russia, therefore, would be subject to repeated inundations, and would become clothed with extensive sheets of sand.

While these conditions obtained, the formation of dust-deposits must have been precluded. In a word, the loess of middle and south-eastern Europe could not have been generated and spread out over

those regions during the climax of glaciation—its formation took place at a later stage. According to M. Tutkoffski, with whom geologists generally will agree, the loess could only begin to accumulate when the great *mer de glace* was retiring. As the latter continued its retreat it left deserts behind it—wide regions overspread with sand and boulder-clay. For a long time, Tutkoffski remarks, these regions must have been devoid of vegetation, owing to the absence of a fertile soil and to the desiccating effect of the glacial foehn. Subject to insolation, to chemical and physical decomposition and disintegration, and to the mechanical action of the wind, the deserted bed of the retiring *mer de glace* could not have been otherwise than a barren desert; Tutkoffski, therefore, speaks of it as the "zone of deflation." The glacial foehn constantly scouring that zone swept up the fine powder or dust of the desiccated morainic and fluvio-morainic accumulations, and transported it far away to south-east, south, and south-west, finally depositing it over a broad tract bordering the zone of deflation. That region of dust accumulation Tutkoffski terms the "zone of inflation." Meteorological considerations and the evidence of organic remains compel us to conclude that this last-named zone must have been a vast region of continental steppes, clothed with vegetation and peopled with a true steppe fauna. Here it was that the foehn, owing to its diminished gradient, gradually died out, depositing its fine dust or loess, in which the

remains of that fauna and the relics of Palæolithic man have been preserved. As the vast *mer de glace* continued to retire, the zones of deflation and inflation necessarily shifted northwards also. Hence in time the zone of deflation, characterised by its desiccated moraines, and barren sands with their glyptoliths or wind-polished stones, was gradually buried under loess. In short, as the zone of deflation moved northwards it was encroached upon *pari passu* by the zone of inflation. But when the margin of the retreating ice reached the northern regions of Europe, and the Baltic and the North Sea began to appear, the climate of the zone of deflation would be rendered more humid or less continental. At the same time as the area covered by the inland ice was being gradually restricted, the foehns flowing out from it would become correspondingly feeble and inconstant, until eventually deflation and the æolian transport of dust would cease. It is for this reason, Tutkoffski remarks, that the range of the loess towards the north is strictly limited. Thus, as he says, the normal loess, which, with its abundant evidence of steppe conditions covers deposits that bear witness to tundra and desert conditions, is as truly a product of the old ice-sheet as its erratics, moraines, and fluvio-glacial accumulations. The difference between it and these deposits is simply this, that the latter tell us of a time when the great *mer de glace* was in the heyday of its might and vigour, while the former is the witness of its decay and dissolution.

Tutkoffski's views apply specially to the enormous accumulations of loess in south-east Europe, which are almost exclusively of æolian origin. The loess of middle and western Europe, however, is not entirely wind-blown. Not infrequently it would appear to be rather of the nature of a flood-loam, and here and there it contains fresh-water shells. The valleys of the Danube, the Rhine, and other rivers descending from the Alps were subject, as we know, to frequent inundations, from which loam must have been abundantly deposited. Nevertheless, the great valleys referred to were likewise swept by winds, and the loess throughout wide tracts has all the characteristics of a wind-blown formation, having yielded, as we have learned, many relics of Palæolithic man and plentiful remains of the steppe fauna. The wind-blown loess of central Europe, like that of south-east Russia, did not begin to form until the tundra conditions of the Glacial period were passing away. But whether it was distributed entirely by northerly winds is doubtful. Under existing conditions foehns descend from the snow-covered Alps, and it is not unreasonable to infer that similar dry but more powerful winds may have swept down from the Alps and other snow-clad mountains during the slow retreat of the great glaciers.

LECTURE VIII

THE TESTIMONY OF INTERGLACIAL FORMATIONS

Evidence of Changes of Climate. Different Types of Interglacial Formations. Examples from Scotland, England, France, Northern Germany, and Central Russia. Interglacial Deposits of the Alps—in Tyrol, Switzerland, and North Italy. Contrast between the Interglacial Floras of Northern and Southern Alpine Lands. Duration of Interglacial Epochs, as measured by Extent of River Erosion. Gibraltar Interglacial Deposits.

FROM my description of the glacial conditions of the Pleistocene period, you must have had no difficulty in concluding that the arctic animals and plants of which I spoke in my first lecture must have lived in Europe during the Ice Age. That indeed is demonstrated by the fact that their remains occur in the morainic and fluvio-glacial deposits of what are now our temperate latitudes. We feel assured, then, that in glacial times the middle tracts of our Continent must have existed as bleak and barren tundras; and that when the great Alpine glaciers and the Scandinavian inland ice began to retire, these tundra conditions slowly changed and were gradually succeeded by a steppe climate, not unlike that of south-east Russia and south-west Siberia in our own day.

But you will remember that warm or genial conditions also characterised some stage or stages of the Pleistocene period, when hippopotamus, elephant, and other animals of a southern habitat roamed over our Continent. The evidence obtained from cave-accumulations and ancient river alluvia clearly indicates, therefore, that alternations of climate took place during Pleistocene times, and we have next to inquire whether the glacial formations have any similar tale to tell.

Well, they have! We know now that the so-called Ice Age was not one continuous period of intense cold, but was again and again interrupted by long spells of more genial conditions. The Pleistocene period was characterised above all by these climatic oscillations. It consisted, in short, of a cycle or succession of glacial and interglacial epochs.

Before proceeding to the description of particular interglacial deposits, it may be well to define what is meant by the term *interglacial.* Originally it was applied to fossiliferous deposits, usually of fresh-water but sometimes of marine origin, which rested upon glacial accumulations of one kind or another, and were covered by similar products of glacial action. For instance, when lacustrine sand and silt, containing fresh-water shells, mammalian remains, and peaty layers with temperate plants were found resting upon boulder-clay and overlaid by another boulder-clay, they were said to be interglacial. The inference

to be drawn from such a succession of deposits seemed obvious. The underlying boulder-clay indicated the former presence of a great glacier or an ice-sheet, which subsequently melted away, and the land then became clothed with temperate vegetation and occupied by large animals. Subsequently the climate again changed and glacial or arctic conditions supervened, as witnessed by the overlying boulder-clay. Geologists who had not themselves seen such successions of glacial and interglacial beds were for some time sceptical as to the interpretation put upon them by their discoverers. Many were the ingenious attempts to explain them away. Sometimes, for instance, it was suggested that the overlying boulder-clay might have slipped *en masse* from some adjacent hill-slope, and so covered up an old lake-bed. When this was shown to be impossible, then doubts were expressed as to whether the upper boulder-clay was really what it seemed to be—a glacial deposit. Eventually, however, when discoveries of interglacial beds had greatly increased—when such successions as I have instanced had been met with in almost every country in Europe which had formerly been glaciated—scepticism could no longer prevail. It was then admitted generally that interglacial beds do occur. The only question that remained to be settled was the extent of the climatic changes they signified. Now, it is obvious that if interglacial beds contained only the remains of a tundra flora and fauna, their presence need not imply any marked

climatic change. Existing glaciers, as we all know, have their periods of advance and retreat. After a succession of mild and dry seasons with a diminished snowfall, alpine glaciers begin to retire, and vegetation by and by invades the area formerly occupied by ice. Eventually severe seasons with a heavy snowfall succeed, and the glaciers readvance and recover the ground they had vacated. In doing so, it is obvious their moraines may here and there come to overlie the soil and plant-remains belonging to the period of temporary glacial retreat.

Such being the case with valley-glaciers, it is probable that similar minor fluctuations of the ice-front may have characterised the great *mer de glace* of northern Europe, and that relics of a tundra flora might now and again come to be enclosed in morainic accumulations. But when interglacial beds are marked by the presence of a flora and fauna indicative of warm-temperate or very genial conditions, it is quite clear that they cannot be thus explained. When the relics of such a flora and fauna are met with in the heart of a formerly glaciated region, embedded in deposits that rest upon and are covered by boulder-clay, the succession can only point to decided climatic changes.

The term interglacial, however, is frequently applied to deposits which are neither underlaid nor overlaid by glacial or morainic materials. Cold climatic conditions, as we have learned, may be indicated by organic remains. Should we encounter in France or

south Germany, for instance, the relics of a tundra fauna and flora embedded in silt or clay, we should conclude that the deposits belonged to the Ice Age. And should two such series of deposits occur in the same place, separated the one from the other by beds charged with the remains of temperate and southern plants and animals, the intercalated beds would be correctly described as interglacial.

It will be understood, therefore, that true interglacial formations may be encountered not only in regions where glacial accumulations occur, but in tracts which we have no reason to believe were ever invaded by glaciers or ice-sheets. To illustrate the mode of their occurrence in glaciated and non-glaciated territories, I may now describe a few typical examples.

Throughout the low grounds of a large part of Scotland two sheets of boulder-clay are recognised, of which the upper and younger sheet is the better developed, extending continuously over wide areas. The lower and older is by no means so continuous, being often entirely wanting. Frequently, however, both boulder-clays occur together — the line of demarcation between them being usually conspicuous, when the face of a section is well exposed. Unfortunately the natural exposures in river-cuttings are often obscured under the debris that falls or is washed down from the upper part of a section. Nevertheless clear sections have been obtained, in which the younger clay sometimes rests directly upon the older clay, the upper part of the latter for a few feet down-

wards often showing a "weathered" aspect. That is to say, it is somewhat discoloured, as if from the chemical action of rain, its ferruginous constituents having become more or less oxidised. This would seem to indicate that the lower boulder-clay had for some time formed a land-surface, before the upper boulder-clay came to be deposited. Still more frequently the two clays are separated by beds of sand, gravel, and silt, which may vary in thickness from a few feet up to many yards. The exact significance of these intercalated beds cannot always be determined. In some cases they may be of infra-glacial origin (*i.e.*, accumulated underneath a *mer de glace*); in other cases they may be torrential or fluviatile, laid down in the light of day at a time when the *mer de glace* represented by the lower boulder-clay was melting away, or spread out at a later period in front of the advancing ice-sheet represented by the upper boulder-clay. Deposits of the kind, therefore, certainly show that there were pauses in the formation of boulder-clay, but they afford no clear evidence as to the duration of the pauses.

Now and again, however, the water-formed beds that separate the two clays have a much more definite tale to tell us. From time to time they have yielded organic remains. Some good examples were formerly disclosed in our own neighbourhood, especially near Slateford, during quarrying operations. Unfortunately these interesting relics of interglacial conditions

have gradually been removed or obliterated as the quarries have extended. Excellent sections were exposed both at Redhall Quarry and Hailes Quarry, where the two boulder-clays were separated by a variable thickness of gravel, sand, and alluvial silt with peat. Among the species obtained from the peat were hazel, the nuts of which abounded, oak, alder, and Scots fir, and many small flowering plants. Along with these occurred elytra of beetles and cadis-cases—the whole assemblage of remains indicating a temperate climate like that of Scotland at present.

The succession of changes indicated by the sections referred to would seem, therefore, to have been as follows:—The lower boulder-clay is the bottom-moraine of an ice-sheet which flowed from west to east, as the carry of its included stones and the trend of glacial striæ in the neighbourhood sufficiently attest. Now, that easterly movement was due to the union of two ice-sheets—one flowing south from the Highlands, and the other streaming northwards from the Southern Uplands. At the time the lower boulder-clay was being accumulated, therefore, all Scotland must have been covered by its ice-cap.

The thick gravel and sand beds, with their large angular and subangular stones and boulders which rest immediately on the trenched and eroded surface of the lower till, speak to us of a time when the *mer de glace* melted away, and when the waters derived from the dissolving ice and snow denuded the bottom-

moraine and rearranged detritus of one kind or another which the ice-sheet had left scattered over its deserted bed.

The interglacial beds occur in hollows of these fluvio-glacial deposits and are indicative of a temperate climate, when perennial snow and ice had either disappeared entirely, or were restricted to the higher elevations of our country.

Immediately overlying the interglacial beds torrential fluvio-glacial deposits appeared. These were probably laid down at a time when the *mer de glace* represented by the upper boulder-clay was beginning to overwhelm the land. That boulder-clay, just like its predecessor, is the bottom-moraine of an easterly flowing ice-sheet, and implies, therefore, that all the Scottish Lowlands were once more smothered in ice.

Similar interglacial beds have been observed in other parts of our country, and the tale told by them is much the same as that just outlined. But climatic oscillations are not evidenced only by the occurrence of fossiliferous deposits intercalated between boulder-clays. In most peat-bogs throughout Scotland we find a succession of floras which tells a like tale of climatic changes. One very common phenomenon is the occurrence in those peat-mosses of two "buried forests," the lower separated from the upper by a variable thickness of peat. Over forty years ago I pointed out that the wide distribution of such buried forests throughout the peat-bogs of the British Islands

and north-west Europe could only be accounted for by climatic changes. The peat in which the "forest beds" are entombed is composed of the bog-moss (*Sphagnum*) and other moisture-loving plants—the whole assemblage of plants being indicative of humid and relatively cool conditions, while the buried forests, on the other hand, imply a drier and more genial climate. Within the past few years these general conclusions have been strongly supported by the researches of a well-known botanist, Dr F. Lewis, who, during a careful examination of the peat-bogs in every part of our islands, has detected a definite layer of arctic-alpine plants intercalated in the peat that separates the lower from the upper forest-bed. We can no longer doubt, therefore, that climatic changes took place during the formation of our peat-bogs.

I may now cite one or two examples of similar phenomena met with in England. There, just as in Scotland, we encounter interglacial deposits amongst the accumulations of the Ice Age. Near Hull, for instance, occurs a thick series of gravel and sand, charged with fresh-water shells, amongst which the old river-shell, *Corbicula fluminalis*, is conspicuous. That species is now extinct in Europe, but still lives in the Nile and various rivers of Asia. It is of common occurrence, it may be remembered, in the Pleistocene river-alluvia of the Thames and the Seine, where it is associated with extinct and exotic mammalia. The fresh-water beds at Hull are known to be younger than the oldest boulder-clay of

Yorkshire, and are directly overlaid by another and later boulder-clay. They are thus of interglacial age.

The Pliocene and Pleistocene deposits of Norfolk have long been famous amongst geologists, and are of special interest as containing the records of the first approach of glacial conditions. The Pliocene strata are for the most part of marine origin—the fossils met with in the oldest member of the series clearly indicating a warm-temperate climate. But as we pass upwards in the series, northern types of life begin to appear and gradually increase in numbers, while at the same time the southern types, so dominant in the older strata, gradually vanish. When at last we reach the upper member of the series (Weybourn beds), we find the marine molluscan fauna presenting a thoroughly arctic aspect. Overlying these arctic shell-beds certain fresh-water and estuarine strata known as the "Forest-bed series" are next encountered. The deposits in question are essentially of fluviatile origin, and are often crowded with drift-wood and tree-stumps. The latter were formerly supposed to occupy the place of growth and to indicate an old land-surface; hence the name of the series, but the stumps in question are now believed to have been drifted. Traces of an old soil, however, do occur in the series. Plant remains are plentifully present—all belonging to living species, and with few exceptions still indigenous to Norfolk. The general assemblage shows that the climate of East Anglia had now become mild and moist, and little if at all

colder than it is to-day. The associated mammalian remains are of great interest: they include those of elephants (*Elephas meridionalis*, *E. antiquus*), hippopotamus, rhinoceros (not the woolly rhinoceros), horse, bison, boar, and many kinds of deer, bears, sabre-toothed tiger, hyæna, wolf, and others.

Above the Forest-bed series come marine deposits containing arctic shells, while these arctic marine beds are in turn succeeded upwards by a fresh-water stratum charged with the relics of an arctic flora, amongst which we note the polar willow (*Salix polaris*) and other northern plants.

Here again we have clear evidence of climatic oscillations. The Weybourn beds underlying the Forest-bed series introduce us to a North Sea tenanted by a well-marked arctic fauna. The Forest-bed series, on the other hand, implies decidedly temperate conditions: while the succeeding deposits just as certainly bespeak a relapse to an arctic climate.

The next example I cite is of peculiar interest from our present point of view, inasmuch as it shows the relation of Palæolithic man to those changing climatic conditions. At Hoxne, in Norfolk, a few miles from Diss, a brick-clay has been worked for many years. So far back as 1797 stone implements were recorded and figured as having been found in this clay-pit, and the figures are clearly those of Palæolithic tools. This interesting discovery, neglected for upwards of sixty years, was recalled

in 1859 when British geologists and archæologists were flocking to the Somme valley to inspect the remarkable "finds" of similar implements in the Pleistocene river-gravels of that region. On visiting Hoxne, Mr (afterwards Sir John) Evans and Professor Prestwich found that the implements had come from one of a series of fresh-water beds occupying a hollow in the surface of a boulder-clay. From time to time since then the old clay-pit has been examined by geologists, and arctic and temperate plants have been obtained from the deposits; but it was not till 1896 that a thorough examination of the place was made by a committee appointed by the British Association. Thanks to the efforts of that committee we now know the precise conditions under which the fresh-water beds were deposited, and their relation to the boulder-clay. A series of trial pits and borings showed that the fresh-water beds occupied a narrow channel excavated through glacial deposits, and were underlaid throughout by boulder-clay. The bottom beds of the fresh-water series consisted of lacustrine clays containing abundance of plant-remains, and were succeeded upwards by a bed of lignite, over a foot thick. The facies of the flora was decidedly temperate—a large proportion of the species being still indigenous. Above that lignite came thirteen feet of dark carbonaceous loam and sand, charged with the relics of an arctic flora. Temperate conditions had thus eventually given place to a climate probably not unlike that of the cold

treeless regions of North America and Siberia. At the top of the whole series lies the brick-clay which has so frequently yielded flint implements. A few mammalian bones and several species of molluscs occur in this deposit, but none of these are specially characteristic either of northern or southern habitats. The molluscs, with a single exception, are all still natives of the district, while the few mammals are widely migrating species. We need only note that while they certainly do not point specially to an arctic climate, they are quite in keeping with temperate conditions.

From the facts thus briefly recapitulated we learn that after the final dissolution of the great *mer de glace* represented by the bottom-moraine known as the "great chalky boulder-clay," the climate of East Anglia eventually became quite temperate. Whether man lived in the region at that time we do not know —no trace of his presence having hitherto been met with in the beds containing the abundant temperate flora. Neither have any Palæolithic implements been discovered in the succeeding arctic-plant beds. It is only in the overlying brick-earth beds that such relics appear.

Let me now recall for a moment the occurrence of the arctic plant-bed in the Pleistocene river-drifts of the Thames valley. That plant-bed, it will be remembered, overlies river-gravels from which Palæolithic implements have frequently been obtained, and these gravels certainly rest upon and are there-

fore younger than the boulder-clay of the same region. I shall not at present stop to consider whether the arctic plant-beds of Hoxne and the Thames valley are of the same age. Certain considerations show that they can hardly be so; it is enough, however, to recognise the fact that great alternations of climate took place in Pleistocene times, and that man was certainly present during at least some of these remarkable changes.

We may next turn our attention to the interglacial deposits of the Continent. The river-drifts of the Seine and the Somme have yielded, as we have seen, the same assemblage of organic remains and Palæolithic relics as the corresponding deposits of the Thames valley, and must therefore be assigned to glacial and interglacial times. In my first lecture I referred to the tufa of La Celle (see Fig. 9, p. 233)—so famous for its abundant plant-remains, which include fig, box, judas-tree, Canary laurel, and many other species indicative of a climate as warm as that of the Dalmatian coast-lands. This tufa overlies the Pleistocene river-gravels, and is itself covered by a sheet of loess—there can be no doubt, therefore, as to its geological position. It is worth noting that the plants in the upper part of the tufa indicate a somewhat cooler climate than those in the lower portion of the same formation. From the upper part Acheulian artifacts have been obtained. Although no glacial accumulations occur in the valley of the Seine near Paris, we do not hesitate to

describe the tufa of La Celle as an interglacial formation—for its geological position is determined by the character of its organic remains. There are many other cases of interglacial deposits which occur in regions outside of the glaciated areas. But for my present purpose I may confine attention to such as are closely associated with boulder-clay and other morainic accumulations.

Throughout a wide region, extending from Denmark and the Low Countries through north Germany into central Russia, several boulder-clays are recognised—often separated the one from the other by aqueous deposits, in which remains of the Pleistocene mammalia, shells, and plants have now and again been detected. For instance, in the neighbourhood of Berlin, beds of sand and gravel, resting upon one boulder-clay and covered by another, have yielded remains of southern types of elephant and rhinoceros, together with horse, urus, bison, Irish deer, stag, caribou, wolf, bear, mammoth, woolly rhinoceros, and musk-ox. Here we have a mingling of southern and temperate forms with a few northern types. The deposits would seem to represent a long interglacial epoch, during which the climate changed from genial and temperate to cold-temperate or boreal. In other places the interglacial beds contain many plant-remains, the general facies of which indicates for north Germany and central Russia a temperate climate of a more insular character than the present. Sometimes in these

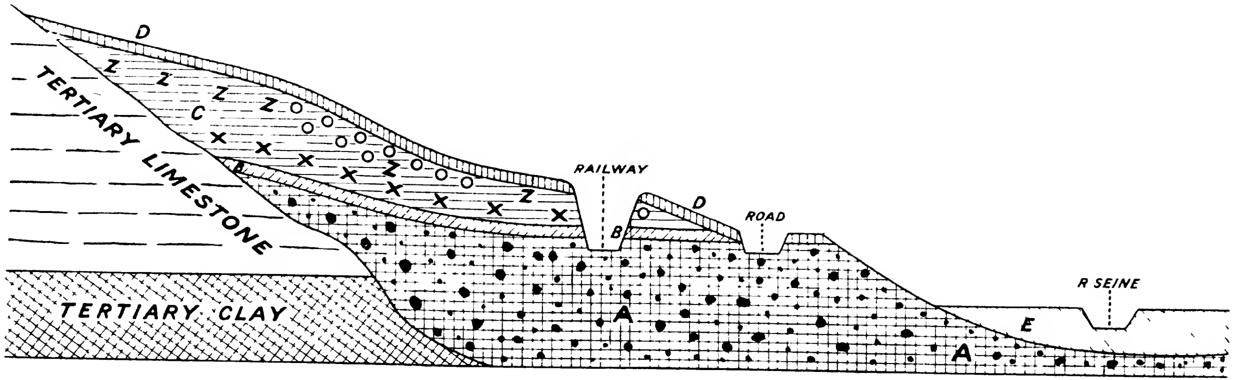


FIG. 9.—SECTION AT LA CELLE-SOUS-MORET. (After Professor Obermaier.)

A, Gravel with remains of *Elephas antiquus*; B, thin bed of clay; C, interglacial bed of calcareous tufa, with fig, Canary laurel, judas-tree, etc., below (x, x, x), and flora indicative of cooler conditions above (z, z, z), and Acheulian implements (o, o, o); D, Loess; E, recent river alluvia.

interglacial beds a gradual change in the facies of the flora may be noted as the deposits are followed from below upwards. The bottom beds may yield abundant traces of a mixed forest vegetation, of a temperate character, consisting of such trees as hornbeam, birch, fir, along with pine, maple, lime, hazel, oak, holly, and willows. The assemblage of plants met with in the next succeeding layers is often suggestive of gradually changing conditions, for northern or cold-temperate mosses begin to appear, and still higher up we come upon the dwarf birch, but find no trace of lime, maple, hazel, oak, or holly—all of which had vanished at an early stage. I must not omit to mention, however, that the flora occurring in certain beds, resting upon and covered by glacial deposits, has throughout quite a northern or boreal character.

Perhaps the most notable feature of the flora yielded by a large number of the interglacial beds of north Germany is that to which I have already alluded. Its facies implies a well-marked insular or oceanic climate, the occurrence of the holly in the heart of the Continent, where it no longer grows wild, being very noteworthy.

Enough evidence perhaps has now been advanced to show that glacial conditions in north Europe must have been occasionally interrupted. Obviously the great ice-sheet had its periods of advance and retreat. Moreover, the changes of climate implied were so pronounced that we cannot suppose their

effects were confined to northern Europe. If arctic and temperate climates have alternated in the north, we might well expect to encounter evidence of such changes in regions further south. It will be necessary, therefore, to see how far those anticipations are borne out by the records of the Ice Age in the Alps and other mountain-regions of middle and southern Europe.

In the great valleys of the Alps, just as in the low grounds of northern Europe, several distinct boulder-clays or bottom-moraines occur, and these, like the corresponding formations of the north, are often separated by aqueous deposits which are sometimes fossiliferous. In short, interglacial beds have been detected in many places throughout the Alpine lands, one or two examples of which I shall now describe.

At Hötting, on the left bank of the Inn opposite Innsbruck, occurs a thick sheet of breccia of angular and subangular rock-fragments, which obviously owes its origin to the action of mountain-torrents. Beginning at a height of several thousand feet above the valley it sweeps down the mountain-slopes, and spreads over a well-marked terrace that rises some 430 feet above the Inn. As this breccia clearly overlies a bottom-moraine and is covered by a younger morainic accumulation of the same nature, it is obviously interglacial.

The underlying bottom-moraine tells us of a time when the Inn valley was occupied by an

enormous glacier, to which local ice-streams descended from all the lateral valleys and mountain-slopes. Professor Penck estimates the snow-line at this stage to have been nearly 4000 feet below its existing level. The whole of the Inn valley was then occupied by a gigantic glacier which, escaping from the mountains, dropped its terminal moraines far out upon the low grounds beyond.

The interglacial deposits overlying the bottom-moraine of that enormous ice-flow have yielded a large number of plants. Many of these, having been buried in fine-grained material, are in an excellent state of preservation. Over forty species have been determined, twenty-nine of which are still native to the region or occur in other Alpine valleys. Six species flourish at present in north Tyrol, but are no longer found growing as formerly at a height of 4000 feet above the sea. More notable still are certain forms, six in number, which are now quite foreign to the Alpine lands. One of these exotic plants most abundantly present in the interglacial beds is the Pontic alpine rose (*Rhododendron ponticum*). This species at present grows wild in south-west Spain, in the Caucasus, and in regions on the southern borders of the Black Sea. In the countries which are now its habitat, the snow-line occurs at a height of nearly 9800 feet. We could hardly expect it to flourish, therefore, in the Inn valley under existing conditions, when the snow-line does not exceed 3700 feet. One of its associates in the

interglacial beds is the box (*Buxus sempervirens*), a species which cannot endure a severe climate. It grows wild in southern and south-east Europe, and in the regions south of the Black Sea, where it flourishes in the woods, 5800 feet at least below the snow-line. The presence, therefore, of those two plants in the interglacial beds is clearly indicative of a warmer climate than now characterises the Inn valley. Other associated plants tell a similar tale, while the entire absence of the boreal and alpine types that now characterise that region is very striking.

It is interesting to compare the mean annual temperature of the hills where the Pontic alpine rose now lives with that of the Inn valley. In the former the annual temperature is 57° to 65° F., while at Innsbruck (1883 feet above the sea) it is only 47°. The Hötting flora, however, flourished at elevations of 3600 feet to nearly 4000 feet, in places where the mean annual temperature does not now exceed 40°. Were the climatic conditions of that interglacial epoch to return, most of the Alpine glaciers would vanish—only a few would be left clinging to the slopes of the loftiest mountains.

The boulder-clay or bottom-moraine that overlies the interglacial deposits tells the same tale as its predecessor. Once more a gigantic ice-flow filled the Inn valley and deposited its terminal moraines outside of the mountain region.

Interglacial deposits, as I have said, have been

detected in many places in the Alpine lands. Among the earliest recognised were those of Switzerland. At Unter-Wetzikon and Dürnten, for example, a few miles north of Lake Zürich, a lignite or brown coal with associated fresh-water beds has long been worked. The deposits rest upon and are overlaid by morainic accumulations, so that their interglacial position is clearly defined. Among the plants recognised are common Swiss fir, Scots fir, yew, white birch, sycamore, hazel, water-lily (*Brasenia purpurea*)—no longer a European plant—marsh trefoil, etc. This flora is indicative of a warmer climate than now characterises the northern foot-slopes of the Swiss Alps, and its evidence is supported by that of the associated fauna which includes straight-tusked elephant, broad-nosed rhinoceros, urus, elk, and stag.

On the south side of the Alps similar evidence of climatic changes is encountered. Thus in the Val Borlezza are found the relics of an old interglacial lake, resting upon and covered by glacial accumulations. Among the plants occurring in the lacustrine deposits are the box and the Pontic alpine rose—the general assemblage of plants having a somewhat more southern aspect than that of Hötting. Associated with this flora occur remains of the broad-nosed rhinoceros and the stag. The origin of the lake is interesting. The mouth of the Borlezza valley appears to have been dammed up for a long time by the great glacier which occupied Lake Iseo.

Into the barrier-lake thus formed mud and glaciated stones were washed from the side of the glacier. Eventually a great embankment of morainic detritus gathered along the flanks of the glacier, so that when the latter at last melted away, the waters of the lake were still held up. The morainic barrier, consisting largely of limestone debris, became solidified into a hard conglomerate, and endured for a long time after the retreat of the great glacier. A genial climate had now supervened—the surrounding hills being clothed with maple, hornbeam, hazel, elm, box, and the Pontic alpine rose, while the broad-nosed rhinoceros became a native of the district. Eventually, however, these genial conditions came to a close, a great glacier reappeared, and dilating into the Val Borlezza, deposited its moraines upon the surface of the interglacial deposits. Finally, the advent of milder conditions, and the dissolution of the glacier, permitted the river Borlezza to cut the narrow steep trench through which its waters presently rush to join Lake Iseo.

The examples now adduced from the Alpine lands may suffice to show that during Pleistocene times these regions experienced changes of climate as strongly marked as those of more northern latitudes. There are certain differences between the interglacial floras of the northern and southern sides of the Alps worthy of notice. The forests that clothed the mountain-slopes in the north were of the Baltic type, consisting mainly of conifers, oaks, maples, birches,

and hazels. Associated with these, however, were the yew, the box, the water-chestnut, and other types, the presence of which shows that the snow-line could not have been lower than it is to-day. On the southern flanks of the Alps the flora had a marked Illyrian aspect; chestnuts flourished at a height of 2600 feet, the vine grew as it still does along the banks of Lake Iseo, the box abounded, and the Pontic alpine rose (now no longer an Alpine plant) was likewise very widely distributed. Nowhere was this interglacial flora associated with arctic-alpine types. The most notable mammals of the time were extinct forms of elephant (not the mammoth) and rhinoceros (not the woolly species), and the stag.

The changes from glacial to interglacial conditions and back again to glacial necessarily imply a long lapse of time. And this conclusion is still further confirmed by the considerable amount of valley erosion that was effected by the rivers of interglacial times, some of them during such a stage having cut their way down through hard rocks to a depth of eighty feet or even of 100 feet. Similar evidence of interglacial erosion occurs in many of the hilly regions outside of the Alpine area. In central France, for instance, it has been shown that during interglacial times, valleys have been deepened by the rivers for several hundred feet. But these and other evidence of the prolonged duration of interglacial conditions I may leave for the present.

In a former lecture some account was given

of the great limestone-breccias of Gibraltar, and I endeavoured to show that these remarkable accumulations were due to the action of frost, which shattered the rock of the culminating ridge—the debris being carried down the slopes and over the low ground by névé and melting snow and rain. The formation of that notable breccia or solidified rock-rubble took place at two distinct periods, separated from each other by a long epoch of milder conditions. The accumulation of the breccia of the first cold stage had ceased, and the loose agglomeration of grit and large and small blocks had become cemented into an indurated mass long before the formation of the later breccias. Not only so, but torrents had worn deep gullies in the older breccia, and acidulated water percolating through crannies and fissures had gradually opened out a series of subterranean galleries and caves, that penetrated both the breccia and the underlying limestone. All this occurred at a time when Spain projected farther into the Mediterranean than it presently does, and when the climate was mild or genial, as is shown by the character of the mammalian remains that occur in the caves. At the period referred to Gibraltar must have appeared as a verdure-clad alp, towering above the surface of a wide expanse of undulating country that stretched south towards the Barbary coast, with which, indeed, it may actually have been connected. The Rock was then tenanted by the ibex in large numbers, and visited from time to time by rhinoceros, elephant, horse, boar,

and deer, and by bears, wolves, hyænas, lions, leopards, lynxes, and servals, some of which may have made their lair in one or other of its numerous caves. Now and again torrents flowing down the mountain-slopes swept the carcasses and bones of animals into gullies and underground galleries, where they gradually accumulated along with other superficial debris, and became in time sealed up by the action of carbonated water.

Eventually submergence ensued, and the land subsided to the depth of 700 feet or thereabout below its present level. This movement seems to have been interrupted by longer or shorter pauses, during which the sea cut terraces or shelves on the flanks of the Rock—shelves which have been excavated partly in limestone and partly in the old limestone-breccia.

By and by subsidence ceased, and the land was re-elevated, probably in as gradual a manner as it went down. The old sea-shelves were then partially covered by shelly gravel and sand. So far as can be made out, the shells of these beds belong to the same species as are now living in the neighbouring sea, from which it may be inferred that the temperature of the sea during the period of submergence was much the same as it is to-day.

To what extent the land was re-elevated we do not know. It certainly attained a greater height than at present, but whether or not Spain extended as far seaward as it did in the preceding period, can only be conjectured. The sand that clothed the

flanks of the Rock was now acted upon by wind and rain, and to some extent re-arranged—"top-dressed," as it were—so as to form long sloping curtains or taluses, the surface of which here and there became hardened by the action of rain, dissolving the calcareous matter of the shells, and again redepositing it between the grains of grit and sand.

Next cold climatic conditions returned, when the limestone again began to break up under the action of frost, and rock-rubble was carried down as before to the low ground. Large blocks and smaller fragments toppling from the lofty cliffs that face the east, fell upon the sand-slopes—here and there plunging into them, where the process of induration had not been far enough advanced to enable the sand to withstand the force of the impact. In this way the shelly sands were eventually buried completely under a thick accumulation of angular blocks and debris, which having since become thoroughly cemented now presents the same character as the older breccia.

Underneath this newer breccia the shelly sands are often quite indurated into hard rock which has been quarried for building purposes. There still remains a long talus of sand, however, sweeping down from the great cliffs that overlook Catalan Bay. This sand is even yet only partially cemented, for it apparently contains a relatively small percentage of calcareous matter. The blocks discharged upon this slope, therefore, merely sank into it, and now

project above its surface, while many doubtless must have rolled downward to rest at the base of the Rock in regions that are now submerged.

From the samples of interglacial phenomena given you must already have come to the conclusion that they tell the same tale as the cave-deposits and old river-alluvia. It is quite obvious, indeed, that the glacial and interglacial formations must be the equivalents in time of the latter. They are all products of the Pleistocene period—some being indicative of cold, others of genial conditions. The period, in short, was characterised throughout by climatic changes, and we may naturally ask, how many such revolutions occurred, and at what particular stage in the series did prehistoric man first appear in Europe? Fortunately more or less definite answers to these questions are forthcoming. By correlating the geological and palæontological evidence, the general succession of events that took place during Pleistocene times has been ascertained. In my next two lectures, therefore, I purpose giving an outline of that history.

LECTURE IX

THE HISTORY OF THE PLEISTOCENE PERIOD

Climatic Conditions of Late Pliocene or Preglacial Times. First Glacial Epoch, or "Scanian" of Northern Europe, and "Günzian" of the Alps. First Interglacial Epoch: Oldest Human Remains. Second Glacial Epoch, or "Saxonian" of Northern Europe, and "Mindelian" of the Alps. Second Interglacial Epoch: Chellean and Acheulian Stages. Third Glacial Epoch, or "Polonian" of Northern Europe, and "Rissian" of the Alps: Mousterian Culture-stage. Third Interglacial Epoch: Mousterian Culture-stage ends. Fourth Glacial Epoch, or "Mecklenburgian" of Northern Europe and "Wurmian" of Alps; Aurignacian, Solutréan, and Magdalenian Culture-stages.

In the Pliocene period—that is, the age immediately preceding the Pleistocene period—Europe experienced climatic conditions differing somewhat from those of the present. From the character of the Pliocene flora it may be inferred that the climate was not only genial but very equable. That flora was richer in genera, and some of those genera were richer in species, than is the case with our existing flora. The forests of Pliocene times were singularly uniform, the same species of trees flourishing contemporaneously in Tuscany and southern and central France. The great forests of the period, according to Saporta,

occupied the plains, the margins of rivers and lakes, and extended up the valleys to the crests of the mountains, without much change of character. The ivy, the platanus, the liquidambar, various maples, and many walnut trees, elms, hornbeams, laurels, sassafras, and others ranged from central Italy to the heart of France. It was an abundant vegetation, composed for the most part of great trees, some of which were destined erelong to become extinct; some again were special forms belonging to genera that are now exotic; others were species which have survived to the present in more southern and eastern regions; while yet others are still represented in Europe by identical or very closely allied species.

Among the great mammals of the time were dinotherium and mastodon. Various extinct forms of elephant and rhinoceros also flourished towards the close of the period, and with these were associated hippopotamus, primitive horses, and the sabre-toothed tiger. During the same period the shores of north-west Europe were washed by genial waters, in which lived many molluscs that are now confined to the seas of more southern latitudes.

It is in the marine deposits of the Pliocene of East Anglia that we read the evidence of that gradual deterioration of climate which eventually culminated in the first glacial epoch. In the older Pliocene strata southern forms of life are present in great force, but these gradually become less numerous as we follow them into the overlying beds; while at the

same time immigrants from boreal regions begin to appear, and continue to increase in number as we approach the later accumulations of the Pliocene sea, until at last the whole molluscan fauna becomes thoroughly arctic. The occasional occurrence of erratics in the earlier Pliocene strata shows that ice-rafts, or possibly icebergs, floated in the North Sea before its fauna had become completely arctic.

The Scanian or First Glacial Epoch

The Pleistocene period thus begins with the advent of an arctic climate—the deposits known as the Chillesford Clay and Weybourne Crag of Norfolk representing the Scanian or First Glacial epoch. At this early stage a cold current coming from the Northern Ocean must have passed southward along our western shores, just as in our day the Labrador Current washes the east coast of Canada and the New England States. Under such conditions perennial snow-fields and glaciers could hardly fail to have flourished in Britain, although (for reasons that will presently appear) we are unable to point in this country to any morainic accumulations belonging to this earliest glacial epoch. Elsewhere, however, such deposits are met with, as in Scandinavia, northern Germany, and the Alpine lands, from the geographic distribution of which we gather that the development of ice-action at this first glacial stage of the Pleistocene was of very considerable importance. The Scandinavian peninsula seems at that time to have supported

a great ice-sheet that not only occupied the basin of the Baltic, but overflowed Scania—the southern part of Sweden—and extended as far south as Hamburg and Berlin. Again, in the Alpine lands strong evidence is forthcoming to show that at the commencement of the Pleistocene period glaciers passed down all the great mountain valleys to the low grounds of the foreland—a state of glaciation implying a depression of the snow-line below its present level of about 4000 feet. This is known as the Günzian stage of the Alpine lands. It is certain, therefore, that the First Glacial epoch was one of pronounced severity. Owing, however, to succeeding glacial invasions, the records of that earliest cold stage in Britain have either been destroyed or buried underneath later glacial formations—at all events they have not yet been recognised.

The Norfolkian or First Interglacial Epoch

The Norfolkian epoch is so termed since its most important records are furnished by the Forest-bed series of Norfolk. These deposits have already been described, and it may be remembered that they consist of fresh-water and estuarine beds which overlie certain marine strata containing arctic shells. The position occupied by the Forest-bed shows that at the beginning of the earliest interglacial stage the sea had retired from the English coast-lands. All the evidence, indeed, leads to the belief that after the disappearance of that cold sea with its arctic

fauna, the southern part of the North Sea basin had become land. Britain was joined to the Continent, and the Rhine, with the Thames as a tributary, continued its course northwards over regions which have long been submerged. It is not improbable, indeed, that the fresh-water Forest-bed series represents the alluvia of that ancient Rhine. The general facies of the Forest-bed flora implies a temperate climate, somewhat similar to that of the present, but probably a little warmer; and the testimony of the plants is in keeping with that of the fauna, amongst the more notable animals being hippopotamus, elephants (*Elephas meridionalis*, *E. antiquus*), Etruscan rhinoceros, great beaver, primitive horses, giant fallow deer, bison, and the sabre-toothed tiger. The earliest interglacial fauna thus included several well-known Pliocene types, some of which appear not to have survived to any later date.

Traces of the Norfolkian stage are met with here and there on the Continent, as in the Low Countries, France, Germany, and Italy. The deposits referred to are recognised chiefly by the character of their mammalian remains, which are essentially the same as those of our Forest-bed series. Certain other alluvia of very early Pleistocene age ought perhaps to be assigned to the Norfolkian interglacial epoch. Of these by far the most notable are the sand-beds at Mauer, near Heidelberg, from which have been obtained the oldest skeletal remains of man hitherto met with on the Continent. This fossil—a lower

jaw—was discovered at a depth of seventy-eight feet from the surface, in river-deposits from which have come several Pliocene mammals—namely, Etruscan rhinoceros, two species of bear, a primitive horse, and other forms recorded from our Forest-bed series, such as the straight-tusked elephant (*E. antiquus*), bison, great beaver, etc. Dr Schötensack describes the mandible as being very massive and without chin projection—quite ape-like in fact—while the teeth, he says, are without doubt human. The geological and palæontological evidence, although not quite decisive, seems to favour the reference of this ancient human type to the First Interglacial or Norfolkian stage.

The Saxonian or Second Glacial Epoch

The deposits immediately overlying the Norfolk Forest-bed are marine, and indicate therefore a readvance of the sea. At first the temperature of the water was such as to favour a marine molluscan fauna similar to that now living off the English coast. By and by, however, the temperature fell, another invasion of arctic molluscs followed, and the sea rose some fifty feet above its present level. Soon thereafter, however, the sea again retired from the Norfolk coast-land, for above the arctic shell-beds we encounter a fresh-water deposit, from which leaves of the arctic willow and other northern plants have been obtained, as well as several land and fresh-water shells. The change of climate, therefore, from that

of the Norfolkian interglacial Forest-bed to that of the fresh-water arctic bed was most pronounced. The lowering of the temperature could not have been less than 20°—a change as great as we now experience in passing from the south of England to the North Cape.

Next in succession to the arctic fresh-water bed come the morainic accumulations that mark the Saxonian epoch—the epoch of maximum glaciation—when the Scandinavian inland ice invaded the low grounds of Saxony, and the vast glaciers of the Mindelian stage of the Alpine succession piled up huge terminal moraines on the forelands (see Map A). The general conditions that obtained in Europe at that stage, having been described in a previous lecture, need not be re-stated. It may suffice to remind you that the Saxonian glacial epoch is well represented in all the mountain ranges and elevated plateaus of the Continent by moraines and fluvio-glacial gravels, while heaps and sheets of rock-rubble and breccia point to the action of severe climatic conditions at lower levels. Flood-loams were then abundantly distributed over the broad valleys and low-lying tracts outside of the glaciated areas. To the same epoch must be referred those Pleistocene marine beds of Sicily and Italy which are charged with a northern fauna. Obviously at that time a cold current washed the west coasts of Europe. Iceland and the Farœ Islands each supported an ice-sheet, and bergs and floes drifted as far south

and east as the Azores, on the depressed coast-lands of which they stranded and dropped their erratics, while boreal and even arctic molluscs invaded the Mediterranean.

The climax of cold having been reached, *mer de glace* and glaciers eventually began to retire, and the low grounds of our present temperate latitudes, relieved of their icy covering, were invaded by a tundra vegetation and roamed over by reindeer, musk-ox, mammoth, and woolly rhinoceros. In middle Europe dry steppe-conditions by and by supervened; but with the continuous retreat of the ice-fields and the improvement of the climate, sand- and dust-storms ceased, and the Tyrolian or Second Interglacial epoch was inaugurated. (See NOTE 11.)

THE TYROLIAN OR SECOND INTERGLACIAL EPOCH

A temperate flora and fauna now began to clothe and people our Continent—the arctic, northern, and sub-arctic forms retiring up the mountains, and returning northward and eastward to their old homes. When this genial epoch reached its climax, a mild oceanic climate prevailed far into the interior of Europe—the snow-fields and glaciers of the Alps being then much less extensive than they are now. Britain at that stage formed part of the Continent, the English Channel and probably a large part of the North Sea being dry land. The equable character of the climate is evidenced by flora and fauna alike. The Pontic alpine rose and its congeners

flourished at elevations in the Alpine lands, where under present conditions they could not exist: while hippopotamus, elephants, rhinoceroses, cervine and bovine animals, and many carnivores ranged over the major portion of Europe. And with this teeming mammalian fauna Palæolithic man was contemporaneous. Just as the land in those days extended farther into the Atlantic than is presently the case, so in the south there would seem to have been one or more land-bridges across the Mediterranean, over which the southern forms passed to and fro (see Map B). While these conditions endured, a larger body of warm water seems to have flowed into the North Atlantic. This may be inferred from the fact that southern molluscs then invaded the Mediterranean just as their boreal predecessors had done in the preceding glacial epoch, when colder water washed the western shores of our Continent.

It was at the climax of this genial interglacial epoch that the Chellean culture-stage prevailed. The race that now occupied middle and southern Europe, and many wide regions in Asia and Africa, are represented by the most primitive of Palæolithic artifacts. These rudely fashioned stone implements seldom occur in caves, but are often met with in the older Pleistocene river-drifts. From this it has been inferred that Chellean man probably lived in the open, for the climate was clement and equable, the seasons not being so strongly contrasted as in our day. The margins of the rivers were apparently

favourite haunts of the race—the coarse gravels affording an inexhaustible supply of the stones required for implements.

The genial conditions of the protracted Tyrolian epoch eventually began slowly to give way. The hippopotamus and its associates, the straight-tusked elephant and the southern elephant, migrated southward, and the last-named species, it may be added, never returned. Temperate and northern types now became the most notable denizens of north-west and middle Europe, the mammoth and the woolly rhinoceros being especially characteristic. Meanwhile the Chellean had been succeeded by the Acheulian culture-stage.

The records of the Tyrolian stage are met with at many places in Britain—both in caves and river-alluvia. In Victoria Cave, near Settle, for instance, remains of the southern and temperate mammalia occur, as hippopotamus, rhinoceros (not the woolly rhinoceros), straight-tusked elephant, bison, red deer, hyæna, etc. The beds containing these remains are overlaid by the fluvio-glacial deposits of the succeeding Polonian ice-sheet. In certain caves in Wales glacial and fluvio-glacial deposits of the same age similarly overlie accumulations which have yielded remains of the Pleistocene mammalia. Sometimes it is the southern group which is represented, while in other cases northern and temperate forms occur, such as mammoth, woolly rhinoceros, reindeer, and horse. Certain caves have obviously been hyæna-dens,

while in several caves Palæolithic implements have been discovered. These finds apparently pertain to the transition stage between the Tyrolian and the succeeding glacial epoch.

Before the close of Tyrolian times the coast-lands of the Baltic had sunk in the sea, and the low grounds of central and northern Britain had likewise been submerged. A certain amount of depression had also been experienced in the Mediterranean region, for to this stage belong the marine terraces cut in the older breccias of Gibraltar. It is probable that the depression in question affected regions lying further to the east, and that the land-bridges which had formerly connected Europe with Africa were now submerged.

The evidence seems to point to the Tyrolian having been the warmest, as it was apparently the most protracted interglacial epoch. This is indicated by the character of the fauna and flora, and by the very considerable geographical changes just referred to—changes which affected both northern and southern Europe. Its prolonged duration is further shown by the profound modifications brought about during the epoch by the slow operation of denudation. This latter is the kind of evidence which appeals most strongly to the geologist—for its meaning cannot be misunderstood. It is just possible that the crustal movements of Tyrolian times may have been more rapidly accomplished than we suppose. But we have no reason to believe

that rain and rivers were more active during an interglacial epoch than they are in our own day. We know how slowly they work, and how after the passing of many generations the face of the land remains practically unchanged. We cannot but be astonished, therefore, when we realise how greatly the configuration of the land became modified during the occupation of our Continent by Chellean man. The whole surface was lowered—in some places by not less than fifty or one hundred feet—while the excavation of many river-valleys was far advanced, and in certain cases well-nigh completed in Chellean times.

The Polonian or Third Glacial Epoch

The cold conditions that characterised the close of the Tyrolian stage obviously signalled the approach of another glacial epoch—the Third or Polonian. Doubtless the transition from the Tyrolian to the Polonian was very gradual, and it would seem that before the climax of the latter had been reached the men of the Mousterian stage of culture had come to occupy the caves of north-west, central, and southern Europe. In England, Belgium, France, and Germany he was eventually contemporaneous, not only with mammoth and woolly rhinoceros, but with reindeer, glutton, arctic fox, and other members of the tundra fauna. He must have witnessed the gradual invasion of the low grounds of north-western and northern Europe by

the third great Scandinavian *mer de glace*. North Britain and Scandinavia would appear at that time to have been almost as deeply buried in ice as during the Saxonian epoch, but the *mer de glace* did not reach the limits attained by its predecessor in England, north Germany, and Russia. The direction of ice-flow differed in some important respects from that of the Saxonian ice-sheet. While the Baltic basin seems to have had relatively little influence upon the course followed by the latter, the direction of the succeeding Polonian ice-sheet was to some extent controlled by that great depression. Similar notable differences in the trend of the two ice-sheets have been elsewhere detected. In southern Scotland, for instance, the track of the later *mer de glace* did not coincide with that followed by the earlier and greater ice-sheet, but in several places crossed it at nearly right angles. So again, while the Saxonian ice-sheet flowed approximately south across Denmark and the southern part of the Baltic basin into Holland and north Germany, the Polonian ice-sheet traversed those regions in a more westerly or south-westerly direction.

The Saxonian *mer de glace*, as already indicated, had reached south in England to the valley of the Thames, but the succeeding Polonian ice-sheet did not extend beyond the Midlands. We are not without direct evidence, however, that an arctic climate at the same time characterised southern England. The succession of deposits at Hoxne in

Suffolk shows quite clearly that such was the case. Here we see certain fresh-water beds, charged with plentiful remains of a well-marked temperate flora, resting directly upon the bottom-moraine of the great Saxonian ice-sheet. These particular beds are in their turn overlaid by a series of loamy deposits which have yielded a characteristically arctic flora. We cannot doubt, therefore, that the underlying beds with their temperate plants are of interglacial age—belonging probably to a late stage of the Tyrolian epoch—while it may be safely inferred that the superjacent arctic-plant beds are of Polonian age. The latter indicate, in short, that tundra conditions prevailed in the south of England when the northern parts of Britain were shrouded in ice.

While this notable recrudescence of glacial conditions was in progress in the north, the snow-fields of the Alps likewise increased in extent, and mighty ice-flows once more filled the mountain valleys and deployed upon the forelands. This third cold epoch of the Alpine lands is known as the "Rissian stage." It is remarkable that the Rissian glaciers in certain valleys were larger than those which had occupied the same valleys in the preceding Mindelian epoch. In other valleys, however, the reverse was the case, the Mindelian glaciers having attained a greater development than their successors in the later or Rissian epoch. In the valleys of the Inn, the Salzach, and the Iller, for example, the

Mindelian glaciers were the greatest, but such was not the case with the Isar glacier, which was most extensive in the Rissian epoch. So again in the Rhine region, in Switzerland, in the French Alps, and in the Po valley the Rissian glaciation was the more extensive. Professor Penck thinks it not unlikely that these differences may have been the result of those differential crustal movements which are admitted to have affected the Alps during glacial times. If Switzerland experienced a movement of elevation in the interglacial epoch that followed the Mindelian glaciation, the Rissian glaciers in the west and south-west Alps would naturally attain larger dimensions than their predecessors of the earlier glacial epoch. Should subsequent research establish this conclusion, it would follow, according to Professor Penck, that the greatest depression of the snow-line must have taken place in the Mindelian epoch—in other words, we should assign the maximum cold of the Glacial period to that stage. So far as northern Europe is concerned, there is no doubt that the Polonian ice-sheet, enormous as it was, did not occupy so wide an area as its Saxonian predecessor. (See Map C.)

The Polonian or Rissian epoch has left its mark upon all the mountain groups and ranges of middle and southern Europe, in the valleys of which more or less conspicuous terminal moraines of that age appear. The physical conditions which had characterised the non-glaciated tracts of our Continent

in the Saxonian or Mindelian epoch were repeated during the subsequent Polonian or Rissian epoch. The Rock of Gibraltar, for instance, had been re-elevated, and thereafter a new formation of breccia took place—the screes of the period covering the beach deposits of the preceding interglacial stage. In many other extra-glacial regions the accumulation of rock-rubble went on apace, and under the influence of frost and thaw soils and subsoils slipped and flowed. With each recurring summer the turbid rivers rose in flood, and inundated wide districts, and gravel, sand, and silt were deposited in enormous quantities over all low-lying regions. When the rigour of the secular winter began to abate, and the snow-fields and *mers de glace* to retire from the low grounds, the advance of arctic flora and fauna naturally followed. Tundra conditions, which had characterised wide tracts of middle Europe during the climax of the Polonian or Rissian stage, now spread more and more as ice-sheet and glacier continued their retreat, and fluvio-glacial floods and inundations diminished in importance. The lemming and its congeners occupied what are in our days the most fertile regions of western and central Europe, while the marmot, the ibex, and other alpine types began to retire from the low grounds of Italy. Reindeer, mammoth, woolly rhinoceros, and Mousterian man were now the most notable denizens of our Continent. The Mousterian culture-stage thus appears to have continued throughout the Polonian

or Rissian cold epoch, and, as we shall see presently, flourished to even a later date.

Gradually the climate continued to improve, the arctic flora and fauna slowly migrating northward. Britain again formed part of the Continent, and the western shores of Europe seem to have extended considerably farther into the Atlantic than at present. As tundra conditions waned a steppe flora and fauna gradually invaded our Continent from the east. For a long time relatively dry conditions prevailed over the plains and low grounds of middle Europe. The climate being somewhat extreme and resembling that which now characterises south-east Russia and south-west Siberia, the low-lying tracts in question were doubtless subject to dust-storms in summer and to blizzards in winter. But with the continued retreat of the northern ice-sheet and the diminishing extent of the snow-fields of the Alpine lands, steppe-conditions eventually passed away.

The Dürntenian or Third Interglacial Epoch

The climate now steadily became less markedly continental and more humid, forests extending in all directions until they covered vast areas. A true forest-fauna now dominated in middle Europe, as it probably had done for some time in the western and southern regions of the Continent. With these wide-spread forest conditions, the Third Interglacial epoch reached its climax. Remains of the straight-tusked elephant and the broad-nosed rhinoceros — both

southern forms—occur in several interglacial accumulations of this age. Thus at Pianico in north Italy and at Flurlingen, near Schaffhausen, the bones of the rhinoceros are met with, while remains of both the rhinoceros and the elephant have been found in the lignite-beds at Dürnten, near Zürich. How genial the conditions were in the Alpine lands at this stage is shown by the evidence derived from the cave of Wildkirchli, occurring at a height of over 4800 feet on the Ebenalp, near Säntis. The cave has yielded abundant remains of a well-marked forest fauna along with numerous Mousterian artifacts. It is noteworthy that characteristic members of the tundra fauna are entirely absent, in place of which we have cave-bear, cave-lion, wolf, ibex, stag, etc., all the species named being found in the caves at Mentone, associated there with straight-tusked elephant, broad-nosed rhinoceros, hippopotamus, and Mousterian artifacts. When Mousterian man followed the chase from Wildkirchli, at a height of over 5000 feet, the climate could not have been less temperate, but was probably even more genial than the present; and we need not be surprised, therefore, to find his relics associated with remains of the southern mammalia in the coast-lands of the Mediterranean. Such evidence as we have, however, would seem to indicate that the Third was not so warm as the Second Interglacial epoch. (See NOTE 12.)

Some considerable portion of the river-drifts of the Thames valley ought probably to be assigned to the Third Interglacial stage. The oldest beds of the

series, it may be remembered, are characterised by the presence of Chellean artifacts, and the remains of the southern and temperate group of mammals. To these earliest river-drifts succeeds a very variable series of gravel, sand, and loam, from which Mousterian artifacts have been obtained in large numbers. The associated mammalian fauna is somewhat mixed, but now and again remains of the reindeer are quite abundant, while elsewhere mammoth, woolly rhinoceros, and horse are well represented, the evidence of the mammalia pointing on the whole to somewhat cold climatic conditions. It must not be forgotten, however, that the Palæolithic "floors" described by Mr Worthington Smith as occurring in the high-level river-drifts are likewise of Mousterian age, and are nevertheless characterised by the presence of a well-marked temperate flora. It would thus appear that during the formation of the older river-drifts of the Thames district several changes of climate took place. The Chellean stage we should assign to the Second Interglacial epoch, and the Acheulian to the close of that epoch; while the later gravels with Mousterian artifacts represent the two succeeding epochs, namely, the Third Glacial and the following Interglacial.

The records in the coast-lands of the Baltic of that Third Interglacial epoch consist chiefly of marine deposits — the included shells belonging to species that still live in the western Baltic, the Kattegat, and the North Sea. It would thus appear

that considerable depression affected those regions during some part of the interglacial epoch, most probably when temperate conditions were beginning to pass away. Certain fresh-water deposits in East and West Prussia, occurring on the same geological horizon, have yielded remains of mammoth, woolly rhinoceros, urus, horse, and the great Irish deer.

The Mecklenburgian or Fourth Glacial Epoch

At the commencement of this epoch large glaciers descended all the Scottish mountain valleys, and occupied many of the sea-lochs. The land was less extensive than it is now—the sea, tenanted by an arctic fauna, reaching to 130 feet at least above its present level. Our estuaries were in winter largely frozen over, while in spring and early summer the ice, broken up into floes, often ran aground in shallow water, and confused and contorted the marine sediments accumulating there. Many erratics were by the same agency distributed over the sea-floor, and a similar transport of erratics and rock-rubbish was effected by the icebergs calved by our Highland glaciers. In the Southern Uplands very considerable ice-streams likewise existed, but none of these succeeded in reaching the sea. An arctic flora, comprising the polar willow (*Salix polaris*), dwarf birch (*Betula nana*), mountain avens (*Dryas octopetala*), and other well-marked northern forms, occupied the Lowlands; while in the fresh-water lakes *Apus glacialis* (a phyllopod now met with only in Green-

land and Spitzbergen) flourished exceedingly. The mountains of the sister countries likewise nourished considerable snow-fields and glaciers, while the tundra conditions of the Scottish lowlands were continued far into the south of England, where Mr Warren has lately discovered in the youngest series of Pleistocene gravels in the valley of the Lea, an arctic plant-bed. The occurrence of an arctic flora so far south is sufficiently striking, and shows, as Mr Warren remarks, that the land must have been bleak and almost treeless —"with little more considerable in the way of vegetation than the stunted bushes of the arctic willow and the arctic birch, even these being half hidden in the growth of moss."

This arctic plant-bed is not the only proof of severe climatic conditions having obtained at so late a period in the south of England. For many years it has been known that the Palæolithic river-drifts of the Thames valley are overlaid by much confused sheets of earthy rubble, which have all the appearance presented by the "flowing soils" of Arctic regions. This "contorted drift," as it is called by Mr Worthington Smith, has not only disturbed the upper part of the Pleistocene brick-earths, but has in several places ploughed through them, so as to contort and displace the famous Mousterian "floor." It may be added that we have no direct evidence that Palæolithic man ever re-visited the district, after that cold epoch had passed away.

The conditions on the Continent were not less

severe. The Scandinavian peninsula and Finland were shrouded in ice, and a great *mer de glace* occupied the basin of the Baltic, and piled up large terminal moraines in Denmark, Schleswig-Holstein, the northern provinces of Germany and Russia. The Scandinavian ice-sheet did not, however, as in earlier times, become confluent with that of Britain, the glaciers of Norway now calving their icebergs at the mouths of the great fiords. Somewhat later the Scandinavian peninsula experienced considerable depression, and a cold sea with an arctic fauna communicated across southern Sweden with the Baltic. (See Map D.)

Turning our attention to the Alpine lands, we meet with like evidence of a very considerable recrudescence of glaciation after the close of the Third Interglacial epoch. That Fourth Glacial stage in the Alpine region is known as the "Würmian." It is represented by great moraines and abundant fluvio-glacial gravels, indicative of gigantic ice-flows, none of which, however, were quite equal to the still mightier glaciers of Mindelian and Rissian times.

The younger archæological stages—the Aurignacian, the Solutréan, and the Magdalenian—are closely related to this epoch, the mammalian fauna indicating for the two first-named stages a somewhat cool climate (as in the caves at Mentone and elsewhere), and for the Magdalenian even colder conditions. Probably the two first-named stages

should be assigned to the dawn of the Würmian—to the period of transition from the preceding interglacial epoch, while the Magdalenian belongs essentially to the succeeding glacial epoch. It would seem that in the Alpine lands the Würmian glaciers had commenced to retire before the Magdalenian reindeer hunters appeared in those regions. But for Europe generally we can hardly doubt that the last "reindeer period" coincided with the Würmian or Mecklenburgian Glacial epoch—the climax of that epoch being reached when Magdalenian man flourished in southern France and Spain. His artifacts, however, occur in many other countries—in England, Belgium, Germany, Switzerland, Austria, Russian Poland, etc., and it is not likely that all those lands were occupied contemporaneously. It would seem most probable that when glacial conditions were becoming more and more pronounced in Britain and northern Europe, man would gradually abandon these latitudes for the less rigorous climate of France. But wide regions in middle Europe where tundra conditions prevailed were roamed over by the Magdalenian nomads for a prolonged period—their associates being as usual reindeer, mammoth, woolly rhinoceros, and their arctic-alpine congeners. Eventually, as the climate changed and the snow-fields began to diminish, the same regions were invaded from the east by the steppe fauna. But Magdalenian man long continued to follow the chase in the dusty wind-blown tracts of central Europe.

The evidence, however, shows that after a time the northern and steppe animals were gradually replaced by a fauna that betokens the presence of woods and meads. The Fourth Glacial epoch had now passed away, and the Magdalenian hunters had finally disappeared.

Much discussion has arisen as to the cause of this apparently sudden disappearance. Some have held, and many still hold, the opinion that a distinct hiatus separates Palæolithic from Neolithic times. Others again believe that no hiatus exists. They point to certain cave accumulations which they think yield evidence of a transition stage. It is an interesting question, which in the present state of our knowledge cannot be definitely solved. Before we consider the matter, however, it will be necessary to study the geological records of the period that followed upon the close of the Mecklenburgian or Würmian stage, which I purpose doing in my concluding lecture.

LECTURE X

THE HISTORY OF THE PLEISTOCENE PERIOD—*continued*

Later Pleistocene or Post-Mecklenburgian Deposits of Scotland. Fourth Interglacial or "Lower Forestian" Epoch in North-west Europe. Fifth Glacial or "Lower Turbarian" Epoch. Neolithic Man in Scotland. Fifth Interglacial or "Upper Forestian" Epoch. Sixth Glacial or "Upper Turbarian" Epoch. Passage from Neolithic to Bronze and Iron Ages. Post-Wurmian Stages in the Alps. Successive Advances and Retreats of Glaciers. Advent of Neolithic Man. Hiatus between Palæolithic and Neolithic periods, now supposed to be bridged by "Azilian." Reliable and Unreliable Estimates of Geological Time. Conclusion.

THE records of later Pleistocene times are nowhere better preserved or more readily deciphered than in Scotland, and I shall therefore treat of them first. Before doing so let me remind you that the Mecklenburgian or Fourth Glacial epoch is represented in this country by a series of great moraines and fluvio-glacial gravels—the accumulations of considerable district ice-sheets and large valley-glaciers. Our seas, tenanted by an arctic fauna, then stood some 130 feet or thereabout above their present level, while the lowlands were treeless tundras clothed with arctic plants. The raised beaches or marine terraces of the epoch in question are now

conspicuous in our broad lowland valleys, as in those of the Tay, the Forth, and the Clyde, and may be easily recognised at many other places round our coasts.

Amongst the more prominent formations of later Pleistocene age are certain other Raised Beaches, besides Moraines, Alluvia, and Peat-mosses, the relation of which to the accumulations of the Mecklenburgian stage must be carefully noted. The oldest of these younger raised beaches occurs at a height of forty-five to fifty feet above the present sea-level. Like its predecessor (the 100-foot beach) it is best developed in the great estuarine valleys of the Tay, the Forth, and the Clyde. Usually it assumes the form of well-marked terraces of gravel, sand, clay, and silt; but on the more open sea-coasts it is now and again represented by ledges or benches cut in the solid rock. Most of the shells, etc., it contains belong to still indigenous species. Obviously a considerable interval of time separated the formation of this beach from that of the Mecklenburgian stage. Before the forty-five- to fifty-foot beach began to be formed, the characteristic arctic species of the older beach had disappeared from our coasts. Further, there is evidence to show that after the 100-foot beach had been lifted out of the water, it was for a lengthy period subjected to severe erosion, especially in our estuarine valleys. Moreover, it is quite clear that this erosion was effected by rain and rivers when the land stood at a relatively higher level than it

does to-day, and at a date long prior to the formation of the forty-five- to fifty-foot beach. In the valleys of the Tay and Earn, for instance, the accumulations of the 100-foot beach have been extensively trenched and swept away from broad tracts, so that they now form terraces, the bluffs of which overlook the later carse-deposits of the forty-five- to fifty-foot beach. That the erosion referred to was not the work of the sea in which these younger estuarine beds were formed, is proved by the simple fact that the latter do not rest directly upon the denuded deposits of the 100-foot beach. On the contrary, they are separated from these by a widespread sheet of peat, and this is directly underlain by river silt, clay, sand, and gravel.

It is clear, then, that the Mecklenburgian stage was accompanied or followed by a change in the relative level of land and sea. The sea retreated to a lower level than the present, while rivers cut their way down through the deposits of the 100-foot beach, and in time formed broad alluvial flats which were overlooked on either side by the bluffs and terraces of the denuded shelly clays. By and by these younger "haugh-lands" were overspread with dense vegetation, the general character of which betokens a climate not less temperate than the present, the dominant species of trees being oak, alder, hazel, birch, etc. The old land-surface is well represented in the valleys of the Tay and the Earn by a thick layer of woody peat or lignite, from which

rootlets pass downwards into the underlying fluviatile alluvia. The peat, I may add, occurs at and below the present sea-level, and is directly overlaid by the deposits of the forty-five- to fifty-foot beach, which towards their base are crowded with leaves, branches, twigs, and occasional trunks of the trees just mentioned.

Obviously, therefore, the Scottish area again experienced submergence—the sea invading the land up to a height of forty to fifty feet above the present coast-line. In the lower reaches of the Tay valley the carse-deposits belonging to this epoch consist largely of laminated clay and silt. As they are traced up the valley, however, they gradually become more and more arenaceous, until eventually they merge into ordinary river-alluvia, the materials of which become increasingly coarser as they approach the mountains.

Thus it is evident that the passage from Mecklenburgian times was marked by the retreat of the sea and the appearance of a wider land-area than now obtains. And this geographical change was accompanied by a decided amelioration of climate. Subsequently, the land again subsided, and we have striking evidence to show that this movement was accompanied or followed by a relapse to cold conditions. At the head of Loch Torridon, for example, well-formed terminal moraines rest directly upon the forty-five- to fifty-foot beach. To this positive evidence may be added certain negative

evidence. The forty-five- to fifty-foot beach not infrequently fails to appear at the heads of certain sea-lochs in the north-west Highlands, although it may be well developed in their lower reaches. Either, therefore, glaciers at that time occupied the heads of the fiords in question and thus prevented the formation of a beach; or the beach, having been formed before the glaciers reached the coast, may have been subsequently destroyed by those glaciers when they advanced into the sea.

That Neolithic man lived in Scotland during the formation of this beach is proved by the frequent occurrence in it of his relics. At Perth, for example, a dug-out canoe of pine was met with towards the bottom of the carse-clays; and similar finds have frequently been recorded from the contemporaneous deposits in the valleys of the Forth and the Clyde.

The latest conspicuous raised beach occurs at an average level of twenty-five to thirty feet above the sea. The only shells it has yielded belong to still indigenous species, while here and there, as at Oban and in Oronsay, Neolithic artifacts are associated with it. Nowhere, so far as known, do the deposits of this beach merge inland into fluvio-glacial gravels, nor apparently are they anywhere associated with moraines. Often, however, the beach contains trunks and stools of pine and other trees of large size; while now and again it directly overlies peat with trunks and stools of trees that are rooted in an underlying soil. It is hard to say,

however, whether these ancient land-surfaces may not, in some cases, at least, occupy the same geological horizon as the woody peat met with in the Tay valley below the older carse-clays of the forty-five- to fifty-foot level.

Postponing for the present any further remarks on the evidence supplied by these younger raised beaches, I would shortly direct attention to certain other accumulations which unquestionably belong to later times than the closing phase of the Mecklenburgian epoch. I refer to our peat-mosses. Every one knows that these frequently contain the remains of trees. In many places throughout Scotland—as well in high as in low grounds, the peat-mosses cover two forest-beds. Typically, the older forest layer occurs at the base of the peat, while the younger tier of trees rests upon and is covered by a variable thickness of the same material. In some bogs only a few feet may separate the two forest-beds, while elsewhere the intervening peat may attain a thickness of many yards. Long ago I endeavoured to show that the general occurrence of these phenomena was indicative of climatic changes. The forest-beds, I maintained, were the products of relatively dry or continental conditions, while the intervening and overlying sheets of peat were evidence of colder and wetter conditions. I further drew attention to the fact that our peat-mosses are not now in a flourishing condition, but are all more or less rapidly decaying and being denuded by rain

and wind. Under favourable conditions peat is doubtless forming here and there, but this is exceptional, the rate of growth is much exceeded by the general rate of decay and denudation. From this striking fact I inferred that the climate of Scotland had become drier since the formation of the peat that overlies our "upper forest-bed."

The earlier writers on the origin of the Scottish peat did not recognise the influence of climatic changes in the overthrow of the old forests. According to them it was the destruction of the forests that had induced the formation of the peat-mosses, the work of destruction being attributed chiefly to man's hand, although it was allowed that other causes, such as tempestuous winds, might have had their share. The wholesale overthrow of the forests, it was believed, had obstructed the natural drainage of the land and thus brought about marshy conditions favourable to the growth of sphagnum and its allies. More recently it has been suggested that in certain cases the drainage may have been interrupted by the heaping up of banks of sand, clay, etc., across broad valleys, whereby the forests over wide areas may have been destroyed by stagnant water, and thus eventually replaced by bogs. This is a somewhat far-fetched explanation. If it had any evidence in its favour, that should not be hard to point out. Where, one might ask, are those supposed bars or banks behind which the stagnant water is imagined to have accumulated?

That none of these explanations can be accepted as sufficient to account for the phenomena of our peat bogs in general, is shown by the mere fact that the buried forests are not confined to the peat of low-lying and gently undulating ground—to positions, namely, where the drainage might possibly have been disturbed by one or other of the causes suggested. On the contrary, they occur just as constantly in the peat of mountain-slopes and hill-tops, where, owing to the form of the ground, interruptions of the drainage could not possibly take place. Moreover, the almost invariable appearance, in the peat of low and high grounds alike, of two buried forests obviously points to the operation of some widely-acting recurrent cause.

Conclusions similar to mine were subsequently advocated by the late Professor Blytt, who, after a careful study of the peat-mosses of Norway, was convinced that these gave evidence of a well-marked alternation of wet and relatively dry climatic conditions having obtained after the low grounds of that country had been vacated by the "inland ice" of the Glacial period. I need only add that the phenomena of successive buried forests have long been recognised as characterising the peat-bogs of northern and north-west Europe. The occurrence of these trees, however, has been variously interpreted, some authors upholding views that are practically the same as those I had previously ventured to set forth, while others would attribute

the origin of the peat-mosses to the overthrow of the forests by the various causes already referred to.

When we come to inquire into the relation of our Scottish peat-mosses to the glacial deposits, we have no difficulty in ascertaining that they belong to a later date than the Mecklenburgian stage. This is shown by the fact that the peat with its buried trees overspreads the fluvio-glacial gravels and moraines of that epoch. Hence it would appear that our oldest peat-mosses occupy precisely the same geological horizon as the lignite and alluvia which underlie the carse-clays of the forty-five- to fifty-foot level, and directly overlie the deposits of the 100-foot beach. We are thus led to the conclusion that the ancient land-surface buried underneath the carse-clays of the forty-five- to fifty-foot beach is contemporaneous with the Lower Forest-zone of our inland peat-mosses. This correlation gives us the key to the history of all the later climatic and geographical changes experienced by our country.

Summing up the evidence thus briefly stated, we may recognise the following succession of stages in the later Pleistocene history of Scotland:—

The Lower Forestian or Fourth Interglacial Epoch.

After the Mecklenburgian glaciers had disappeared, the land gained in extent, the sea eventually retreating considerably beyond the present coast-line.

The climate at the same time gradually improved until genial conditions supervened, and a strong forest growth covered the low grounds and extended upwards to elevations which trees in our country no longer attain. The relics of that great forest epoch we find in the Lower Forest-zone of our peat-mosses. Hence I term it the Lower Forestian.

The Lower Turbarian or Fifth Glacial Epoch.

Next followed partial subsidence of the land, accompanied ere long by a relapse to cold conditions. Snow-fields now reappeared, and considerable glaciers descended our mountain valleys, and in some places reached the sea. The climate was wet and ungenial, the forests decayed, and bog-mosses gradually usurped their place. To this stage we assign the Lower Peat of our inland bogs, as also the forty-five- to fifty-foot beach, and certain moraines and fluvio-glacial gravels.

The Upper Forestian or Fifth Interglacial Epoch.

The succeeding stage was characterised by re-elevation of the land, and the retreat of the sea beyond the present coast-line. But the land was probably not so extensive as during the earlier forest epoch. This geographical change was marked by the disappearance of perennial snow and ice, and by a return to dry genial conditions, apparently similar to

those that formerly obtained. Forests again clothed the land—flourishing in many places over the surface of the now desiccated peat-mosses. This stage is represented by the Upper Forest-zone of our inland peat, and by the trees which occur under the deposits of the twenty-five- to thirty-foot beach. It constitutes the Upper Forestian.

The Upper Turbarian or Sixth Glacial Epoch.

Once more partial subsidence ensued, and the climate again became somewhat cold and wet. Over wide areas, the forests, as before, began to decay, and were eventually buried under the continually extending peat-mosses. We cannot actually demonstrate that snow-fields and glaciers reappeared at this stage. The latest beach we are able to correlate with the Upper Peat, but that beach is nowhere associated with moraines or glacial gravels. Nevertheless we are not without evidence suggestive of the appearance at this time of inconsiderable glaciers amongst our highest mountains. These small glaciers undoubtedly existed at a later date than the glaciers that dropped their moraines on the forty-five- to fifty-foot beach. It is therefore only reasonable to infer that the high-level corrie-glaciers in question were probably contemporaneous with the formation of the twenty-five- to thirty-foot beach and the Upper Peat of our inland bogs. But the chief evidence of cold wet conditions is unquestionably that furnished by the Upper Turbarian

itself. It covers the Upper Forestian in precisely the same way as the Lower Turbarian overlies the Lower Forestian.

THE RECENT AND PRESENT EPOCH.

The final stage witnessed the retreat of the sea to its present level. The climate now became drier, and peat-mosses ceased to flourish as they had done in the immediately preceding epoch. Thus the final phase of Pleistocene history may be said to be characterised especially by the general decay and denudation of our peat-mosses, the vegetation growing upon which is almost invariably of a drier type than that found in the peat itself.

Did time permit I might follow other lines of evidence, all leading to the conclusion that oscillations of climate marked the closing stages of Pleistocene times. For example, the phenomena presented by the alluvial terraces of our larger river valleys might be cited. It would not be hard to show that during the period in question our rivers have at some stages been most active as eroding agents, while at other stages their chief work has been the transportation and deposition of sediment. During the genial epochs, when the land stood at a higher level than now, the rivers busied themselves especially in deepening and widening their courses, in sweeping away the glacial and fluvio-glacial detritus with which their valleys had been so largely choked. During the cold wet epochs the land was depressed below its present level,

and the larger rivers were then chiefly engaged in filling up the lower reaches of their valleys with abundant sediment. In a word, epochs of dominant erosion alternated with epochs of dominant deposition.

In support of my general conclusions, I might also appeal to certain facts relating to the present and past geographical distribution of animals and plants. The appearance, for example, in the North Atlantic of isolated colonies of southern types of molluscs, surrounded on all sides by boreal and cold-temperate forms, and the occurrence now and again of similar no longer indigenous molluscs in the raised beaches of Nova Scotia, Greenland, Spitzbergen, and Scandinavia, are alike strongly suggestive of warmer conditions having at a very recent period characterised the North Atlantic. Quite in keeping with these phenomena is the fact that the beaches in question are often crowded with southern types which, although still lingering on in these northern seas, do not now attain so large a size as their predecessors of late Pleistocene times, while they are obviously much less abundant.

But the discussion of these and other lines of evidence (especially those afforded by the geographical distribution of plants in temperate Europe) would call for more space than is at my disposal.

Although the more obvious proofs of alternating genial and ungenial climates supplied by our peat-mosses seem to me too strong to be resisted, fortified as they are by the evidence yielded by our raised

beaches and recent morainic accumulations, I have yet long been of opinion that they would probably be strengthened by a systematic botanical examination of the peat itself. I could not doubt that a study of the several layers of vegetable matter of which peat-mosses are composed would throw light on the particular character of the climate that obtained during their accumulation. It was obvious to me, although no expert in botany, that bog-mosses were not the only constituents of peat: in many sections I could see what appeared to be a succession of layers made up of the remains of different kinds of plants. And often have I regretted my inability to interpret what that succession meant; for I felt sure it had some interesting tale to tell. Fortunately the work of interpretation was at last undertaken by an accomplished botanist—Dr Francis J. Lewis. His researches were carried on for a number of years, during which he made a careful botanical survey of the peat-mosses of our country, the results of which he brought before our Royal Society in a series of masterly monographs. Space will not allow me to give more than a meagre outline of these results. Suffice it to say that Dr Lewis has demonstrated that our peat-mosses show a definite succession of well-marked stages, corresponding to those I had already established on purely geological evidence. In illustration of the results obtained by Dr Lewis, I must content myself with a brief *résumé* of such of his observations as help us to understand the oscillating

climatic conditions of late Pleistocene times. It may suffice to cite from his account of the peat-mosses of the Southern Uplands and the Highlands.

The Southern Uplands is the general term applied to that belt of hilly and mountainous country which extends from the coasts of South Ayrshire and Wigtownshire to the high grounds that terminate on the East Coast between the valleys of the Tweed and the Tyne. Throughout this broad tract peat-mosses abound, large areas of the higher ground being of a dominantly moorland character. Nowhere are the peat-mosses better developed than in the mountainous district of Merrick in Galloway, and the lofty region in which the river Tweed takes its rise. In these two typical areas the peat-mosses bear the same relation to the glacial and fluvio-glacial deposits —they everywhere overlie the moraines and morainic detritus of the Mecklenburgian stage. According to Dr Lewis, the first well-defined zone at the base of the peat in the Southern Uplands is a solid layer of the remains of white birch (*Betula alba*), mixed with such plants as heather (*Calluna vulgaris*) and willow (*Salix repens*). Dr Lewis thinks it is hardly possible that this zone represents the primitive vegetation which covered the Uplands immediately after the disappearance of glacial conditions. The first comers would naturally be arctic types, the preservation of which, however, would entirely depend upon climatic and local conditions. In the Merrick district Dr Lewis observed that in many places a thin layer of peat

occurred immediately underneath the birch zone; but unfortunately the material was in too decomposed a condition to allow of the identification of any particular plants. This structureless peat might, as he thought at the time, represent the primitive vegetation of the district—a view which has been strengthened by his later researches in other parts of Scotland, where a definite layer of arctic-alpine plants occurs at the very bottom of the oldest peat-mosses, resting upon morainic materials (Mecklenburgian) and covered by the Lower Forest-bed.

The birch zone at the bottom of the peat-bogs in the Southern Uplands is directly overlaid by a thick stratum of peat, composed entirely of bog-moss (*Sphagnum*). This succession is constantly repeated throughout the region, alike in the peat at the bottoms of valleys, and in that upon steep hill-sides and flat hill-tops. The Sphagnum-bed thus bears witness to a general increase of precipitation; it represents, in short, a change from birch-forest conditions to wet moorland.

As successive layers of the peat are followed upwards, Dr Lewis finds that the bog-moss gradually gives place to cotton-grass (*Eriophorum vaginatum*) and rushes (*Scirpus*). After these plants had flourished for some considerable time, a decided change of climate supervened. In the Merrick district the cotton-grass peat is covered by a dense layer of the stems of crowberry (*Empetrum nigrum*) and two characteristic arctic willows (*Salix herbacea*

and *S. reticulata*). The same zone is represented in the peat of Tweedsmuir by the crowberry and the creeping azalea (*Loiseleuria procumbens*), the latter being a typical arctic form. The constant appearance of this remarkable zone throughout the Southern Uplands can have only one meaning—it points unmistakably to a decided decrease of temperature. It indicates a stage during which the valleys of southern Scotland were characterised by a climate as rigorous as that now experienced on the summits of our loftiest mountains.

The gradual dying away of this cold epoch and the reappearance of forest vegetation are, according to Dr Lewis, faithfully chronicled in the peat. The crowberry, the arctic willows, and the creeping azalea give place above to cotton-grass, and this in its turn to bog-moss or sphagnum—a succession common to the peat throughout the Southern Uplands. Eventually the wet moorland conditions indicated by the sphagnum-peat passed away; the bogs dried up and were invaded by trees, by forests of pine in the Merrick district, and forests of white birch in Tweedsmuir.

Finally, the conditions again became adverse to forest-growth, and the trees of this upper zone were gradually buried under a stratum of peat, consisting chiefly of rushes, bog-moss, and cotton-grass.

In comparing the peat-mosses of the Southern Uplands with those of the Northern Highlands, Dr Lewis finds that the latter, in many places, begin

their history at a later stage than the former. Thus at high levels none of the beds underlying the second zone of arctic plants in the Southern Uplands puts in an appearance. The reason for this is obvious. The recurrence of cold conditions indicated by the arctic plants of the Southern Uplands was more strongly marked in the Northern Highlands. In those elevated regions considerable snow-fields and glaciers reappeared, and all peat-beds representing the Lower Forest-zone of southern Scotland were swept away. As these glaciers in the north began to retreat, a vegetation like that of the tundras invaded the formerly glaciated tracts. Arctic willows (*Salix reticulata* and *S. herbacea*) at first were dominant forms, but these gradually gave place to sub-arctic types (*Salix arbuscula*, *Betula nana*, *Empetrum nigrum*, etc.). By and by this sub-arctic brushwood disappeared, and was succeeded by a close growth of cotton-grass and bog-moss, interspersed with some scraggy birch. That humid conditions eventually became intensified is suggested by the fact that the birch in its turn vanished, and sphagnum alone continued for a long time to occupy the ground. These wet moorland conditions next passed away, the thick sphagnum-peat drying up, and eventually supporting a forest of large pines with an undergrowth of common heather. The great pines of this upper zone, it may be mentioned, flourished at elevations between 2000 and 3500 feet above the present sea-level. Finally they decayed and were

gradually buried under peat, consisting chiefly of bog-moss and rushes.

At lower levels in the Highland area the series is more complete—the tale told by the peat-bogs beginning with the first Arctic plant-bed and Lower Forest-bed, after which comes the Lower Turbarian with the second Arctic plant-bed, followed in succession by the Upper Forest-bed and the Upper Turbarian. It may be noted further that in Shetland the first Arctic plant-bed and the Lower Forest-bed make their appearance, while the Upper Forest-bed is absent.

My limits will not allow me to enter into other interesting evidence adduced by Dr Lewis. I may mention, however, that he agrees with me that existing conditions no longer favour the general growth of peat. On hill-top, hillside, and in upland valleys alike, the peat, he says, is almost without exception being rapidly wasted away. The vegetation at present covering the peat is nearly always of a drier type than that occurring at slightly greater depths—a fact, he remarks, not without its bearing upon the present denuded state of the "mosses."

Before leaving Dr Lewis's work, I may just in a word point out how strongly the conditions of Forestian and Turbarian times contrast with the present. The upper limits reached in our day by pine and birch may be taken roughly at 2000 feet, although in many districts it lies considerably lower than this. But, according to Dr Lewis, these trees

flourished in Upper Forestian times to close upon 3500 feet. The upper limits of the trees of the Lower Forestian stage cannot be determined, since at the higher elevations of the land the local glaciers of the Lower Turbarian epoch appear to have destroyed all records of the Lower Forest-bed. As regards the range of the arctic-alpine flora we note that at the present time the vegetation in question is confined to heights at and above 2000 feet. But in the Turbarian epochs it descended to within 150 feet of the sea-level. These are striking contrasts which can only be accounted for by considerable climatic changes.

In concluding this brief summary of the climatic vicissitudes of late Pleistocene times, I may shortly indicate some of the more important geographical changes that marked the passage of those times throughout north-west Europe. The Lower Forestian epoch—one of genial conditions—was ushered in by what appears to have been a widely extended movement of elevation. The British Islands were not only united to themselves but to the Continent, while the uplift of the Scandinavian lands converted the Baltic Sea into a great fresh-water lake, the old shores of which are readily traced. The succeeding Lower Turbarian epoch was marked by depression, the British area being separated from the Continent. At the same time considerable subsidence affected the Scandinavian lands, and the Baltic once more became connected with the North Sea. Temperate conditions continued for a time, but eventually the climate

deteriorated, becoming wet and cold. The climax of this epoch was attained when considerable glaciers here and there reached the sea in the north-west Highlands, and an arctic-alpine flora grew down to nearly sea-level. In Upper Forestian times re-elevation of the land ensued, but to what extent is not known. Certainly the British coasts advanced on all sides further than at present, but there is no reason to suppose that our area again became continental. The climate was genial, the forests clothing our Highlands up to a height of 3500 feet —that is, 1500 feet above the present limit reached by pine and birch. The Upper Turbarian epoch, on the other hand, was characterised by cold and wet conditions, during the prevalence of which the horizontal and vertical range of the forests became much restricted. The climate, in a word, appears to have been much the same as during Lower Turbarian times, as may be inferred from the fact that the arctic-alpine flora descended nearly to sea-level. But if the small corrie glaciers of our Highland mountains be referable to this stage, as is most probable, this would seem to indicate less severe conditions than obtained when the valley-glaciers of the Lower Turbarian stage reached the sea and dropped their moraines on the forty- to forty-five-foot beach. The present or closing phase of the long cycle of changes is marked by a higher temperature and drier conditions than those of the Upper Turbarian.

Having now outlined the history of late Pleistocene

times in north-west Europe, typically represented as I believe that history to be by the superficial accumulations of our own country, I would next direct your attention to the contemporaneous records of the Alpine lands. Let me remind you that the Fourth Glacial epoch of those regions is that known as the Würmian, which corresponds to the Mecklenburgian of northern Europe. The passing away of the Würmian stage is indicated by a succession of large moraines and associated river-gravels, which seem to show that the final retreat of the last great glaciers was interrupted by at least three long pauses or "Rückzugstadien." The moraines in question are separated from one another by what are termed "interstadial" deposits, which in character and position simulate interglacial accumulations. Professors Penck and Brückner (who are our chief authorities on the glacial history of the Alps) are very guarded in their interpretation of these phenomena, but are clearly of opinion that the moraines indicate successive advances of the glaciers, each advance having been preceded by a retreat of unknown extent. Named from places at which they are typically displayed, the three series (beginning with the oldest) are known as the Bühlstadium, the Gschnitzstadium, and the Daunstadium. From many observations we learn that during the earliest of these stadia the average height attained by the snow-line was 900 metres below its present level, while in the subsequent stadia it rose successively—reaching in the Gschnitz-

stadium a height of 600 metres below the existing snow-line, and in the Daunstadium rising some 300 metres higher.

The interstadial stages imply long periods of time, during which the glaciers retired up their valleys for considerable, if indeterminate, distances. So far, therefore, they are comparable to the interglacial epochs. In like manner, the moraines of the Bühl, Gschnitz, and Daun stadia are comparable to the similar moraines of the preceding glacial epochs, since each series of moraines, old and young alike, indicates a distinct readvance of the glaciers. Penck and Brückner fully recognise all this, and are even willing to admit that certain interstadial accumulations may eventually come to be recognised as of interglacial importance. In general, however, the evidence is not decisive—the "interstadial" deposits are wanting in any clear indications of true interglacial conditions. Their plant-remains have not yet been exhaustively studied, and until this work has been done, it is considered safer to look upon the deposits in question as indicating less important climatic changes than the interglacial accumulations of earlier Pleistocene times. It is to be hoped, therefore, that the plant-bearing beds will ere long receive the careful attention of competent botanists.

But if the closing stages of the Pleistocene period in northern Europe were characterised by several well-marked climatic changes, we can hardly doubt that similar oscillations occurred contemporaneously

in the Alpine lands. (See NOTE 13.) And the stadial and inter-stadial phases recognised by Penck and Brückner would thus seem to represent our Lower and Upper Forestian and Turbarian stages. According to Penck, the Bühlstadium marks a temporary re-advance of the great Würmian glaciers, and it is interesting to learn that this readvance took place in Magdalenian times. The succeeding Gschnitz and Daun stadia may not improbably represent our Lower and Upper Turbarian stages. It would appear, however, that in the Alpine lands the earliest traces of Neolithic man are of later date than the Daun stadium. Thus the interval between the Bühl and Daun stadia represents, according to Penck, the "hiatus" between the Palæolithic and Neolithic ages. It is never quite safe, however, to rely on negative evidence. Neolithic man was certainly living in Scotland towards the close of the Lower Forestian or the beginning of the Lower Turbarian epoch, and by that time, therefore, he must already have spread over a large part of Europe. So far as we have geological evidence to guide us, it would seem as if his advent did not take place until all the extinct and exotic mammals of Pleistocene times had disappeared. The very earliest Neolithic relics are associated with the remains of a forest and field mammalian fauna, which we recognise as being essentially the same as that now occupying Europe. The last representatives of the Palæolithic period, on the other hand, were the reindeer hunters of

Magdalenian times, who had as their congeners the tundra and steppe groups to which I have so frequently referred. In short, Palæolithic man closed his career in Europe under dry climatic conditions, at a time when vast steppes extended through the heart of the Continent, while Neolithic man did not begin his career until these conditions had passed or were passing away and great forests had invaded the former steppe-lands.

It goes without saying that profound changes of climate do not take place in the twinkling of an eye. The passage from the steppe conditions of late Magdalenian times to the temperate forest-climate which awaited the arrival of Neolithic man, implies most probably a lapse of several thousand years. Are there any geological records of the human race having lived in Europe during that long interval? Up till a few years ago that question could only be answered in the negative. Wherever accumulations of Neolithic age had been found resting upon deposits containing relics and remains of Palæolithic man, a very distinct break always separated the two. Caves, river- and lake-alluvia—all told the same tale of a hiatus in the history of our race Recently, however, certain discoveries have served to some extent to fill up that apparent blank. The first of these discoveries was made by a well-known French expert, the late M. Piette, near Mas d'Azil, a little town at the foot of the Pyrenees, distant about forty miles south-south-west from Toulouse. Here the

river Arize winds for a quarter of a mile through a lofty natural tunnel. The road from St Girons to Carcassonne traverses the tunnel, which is thus readily accessible. For a long time it has been known that accumulations of Magdalenian age are present in the cave and in the side-galleries opening into it, but M. Piette's researches demonstrated the occurrence above these Magdalenian beds of younger deposits, representing a culture-stage hitherto unrecognised. The accumulations dug through by him were over twenty feet in thickness. Towards the bottom of his cutting two culture-beds of Magdalenian age were encountered, the one separated from the other by five feet of laminated river-sand. Both culture-beds contained the usual artifacts; but it was noted that while reindeer remains were very plentiful in the lower bed, and scarce in the upper bed, the remains of red deer abounded in the latter. Overlying this upper bed came four feet of laminated fluviatile silt, and immediately above these river-deposits appeared certain layers which, according to Piette and archæologists generally, represent the transition from Magdalenian to Neolithic times. The lower layer of these transition beds was termed "Azilian" by Piette. The various implements it contained showed no trace of the fine work so characteristic of the artifacts occurring in the underlying Magdalenian culture-beds. The beautifully fashioned spear-heads, slender needles, engraved and carved objects of the pure Magdalenian culture were

entirely wanting—almost the only implements of bone and horn met with in the Azilian consisting of a few of the commonest and simplest forms, such as pins and polished awls or pointers. The most notable Azilian artifacts, however, are the barbed harpoons, which were present in large numbers, Piette having collected over a thousand specimens. These are flat-shaped and made exclusively of stag-horn, and thus differ from the Magdalenian type which was cylindrical and fashioned of reindeer-horn. This is readily accounted for by the nature of the materials operated upon. Stag-horn is internally of a looser or spongier texture than reindeer-horn, and consequently it was only the outer compact rind of the former that could be utilised for harpoons. Most of the Azilian harpoons are perforated at the butt end with a round or oval hole, which is not the case with the older Magdalenian forms. Personal decoration is suggested by shells and the teeth of stag, wild boar, and bear, which are perforated as if for the purpose of being strung and used as necklets. Besides these were found a large number of water-worn pebbles or gravel-stones, painted in red and brown with various designs, such as round dots, simple lines and bands, zigzag lines, crosses, and devices that have a strange resemblance to letters. What these curious markings signify no one can say —although many guesses have been made.

The mammalian fauna of the Azilian is entirely modern—not a trace of the reindeer or its arctic-

alpine associates being met with. The most abundant remains are those of the red deer; other species represented being roe-deer, brown bear, wild boar, badger, wild-cat, and beaver, besides various birds.

The Azilian layer passed upwards into an immediately overlying "transition bed" or "Arisian," as it has been termed by Piette. This culture-bed contained a large quantity of land-shells—*Helix nemoralis*, the brown-lipped snail—and remains of horse, ox, stag, and wild boar. Artifacts of stone, bone, and horn occurred, but stag-horn harpoons were rare: the most notable relics, however, were fragments of pottery. From the great abundance of the brown-lipped snail, which no longer lives in the neighbourhood, it has been inferred that the climate was formerly moister than is now the case.

The so-called Arisian stage is in its turn overlaid by deposits containing relics of later Neolithic, Bronze, Iron, and Romano-Gallic periods, and do not therefore call for further notice.

From the evidence adduced by Piette, we can have no hesitation in assigning his Azilian either to the close of the Palæolithic or to the dawn of the Neolithic age. The reindeer, which had apparently become scarce in late Magdalenian times, had now vanished, and the true forest fauna had taken its place in the Pyrenean foreland. Of this we are well assured from the appearance of the Azilian in many other caves. A number of these caves occur, like that of Mas d'Azil, at the base of the

Pyrenees, and one has been discovered in the Spanish province of Santander. Deposits of the same age are met with further north in several of the Departments of France, as in Landes, Dordogne, Drôme, and Aisne. The Azilian has likewise been detected in Germany, as in caves near Istein and Kleinkems (Baden), where the associated mammalian remains indicate a forest fauna. Other localities in Germany where it has been recorded are the cave of Ofnet, near Nördlingen (Bavaria), and certain caves in Saxe-Meiningen and Westphalia. It has been suggested that the human relics found in the MacArthur Cave, near Oban, may possibly be of the same age. The inference is based on the remarkable similarity of the bone and horn artifacts of the Scottish cave to those of Mas d'Azil—the barbed staghorn harpoons especially closely resemble those of the French Azilian. This is a notable coincidence no doubt, but can hardly be accepted as a proof of contemporaneity. The geological evidence, in point of fact, demonstrates that the Oban relics cannot belong to any earlier date than our Upper Turbarian, while the Azilian must be assigned to the Lower Forestian. The interval between these two epochs thus represents a prolonged period, during which two very considerable changes of climate supervened. (See NOTE 14.)

From what I have said it will be gathered that the Azilian is at present not known to occur in Europe north of the 51st parallel of latitude. In

the many caves of England, Belgium, and middle Europe generally, which have yielded both Palæolithic and Neolithic deposits, the latter are invariably sharply differentiated from the former—there is a decided unconformity or hiatus between the accumulations of the two periods. For the present we can only speculate as to what this means. The evidence of the French Azilian shows that Magdalenian man disappeared while the arctic-alpine fauna was gradually being replaced by the forest-fauna. And the same conclusion, as we have seen, is suggested by the testimony of the Schweizersbild rock-shelter. It is quite possible that Palæolithic man and his Neolithic successor may have come into contact in southern Europe—or, as some suppose, the two may be the same race. On the other hand, it has been suggested that Neolithic man may have been evolved in some extra-European region under a genial climate, and only entered our Continent when the conditions suited his needs. Whether he absorbed or killed out the earlier occupants of the land, or whether they had previously emigrated with the gradually retreating northern fauna we cannot tell, and may never be able to discover.

In the course of these lectures I have now and again referred to certain phenomena, the obvious explanation of which implies the great antiquity of Palæolithic man. Indeed, I shall have spoken to little purpose if the evidence I have laid before you has not prepared you to admit that the history of

the human race in Europe must embrace a vast period. When we reflect on the many geographical changes that man has witnessed—the submergence and re-elevation of enormous tracts—the erosion of valleys and general lowering of the surface by denudation; when we consider that he has lived through a succession of stupendous climatic revolutions; that he has seen widely contrasted floras and faunas alternately occupying our Continent—tundras, steppes, and great forests succeeding each other again and again—we must feel convinced that the few thousand years that have elapsed since the downfall of Babylonian, Assyrian, and Egyptian empires are as nothing compared with the long eons that separate the earliest times of history from the apparition of Palæolithic man in Europe.

As already indicated, there have been many attempts to form an approximate estimate of the duration of the Pleistocene as of other geological periods. No geologist has overmuch confidence in such estimates, but, as I have said, they serve to give some precision to our conception of geological time. And this is especially the case when the computations are based on definite data by experts, who have a competent knowledge of the records of the period involved. It is not altogether improbable, indeed, that we may yet be able to arrive at a reliable conclusion as to the number of centuries that have elapsed since the beginning of the Ice Age. There can be little doubt that the great cycle of

climatic changes of which I have been speaking owed their origin to cosmic causes, and that some day astronomers and physicists may succeed in discovering what these causes were and how they worked.

In the absence of an exact chronological basis, such as astronomy may yet supply, the absolute duration of the Pleistocene cannot be determined. But, as Professor Penck has shown, a careful estimate of the amount of geological work done during the several interglacial epochs may enable us to form some conception of the time involved. If it be justifiable to infer that the greatest amount of work required the longest time for its accomplishment, then it would appear that the genial interval between the Mindel and the Riss glaciations greatly exceeded in duration the preceding and succeeding interglacial epochs. On various grounds the Würm glaciation is conjectured by Penck to have reached its maximum about 20,000 years ago. The evidence goes to show that the immediately preceding Riss-Würm Interglacial epoch was not less than three times as long as the post-Würmian epoch, while the Mindel-Riss Interglacial stage was twelve times longer than that epoch. Thus we have 20,000 years for the duration of post-Wurmian times, 60,000 years for the Third or Riss-Würm Interglacial epoch, and 240,000 years for the Second or Mindel-Riss Interglacial epoch. The data for determining the duration of the First or Günz-Mindel Interglacial

epoch are not so ample—all the evidence, however, leads to the belief that while not so long as the second, it was much longer than the Third Interglacial epoch. We may provisionally assume its duration to have been about 100,000 years, and we thus obtain 400,000 years for the first three interglacial epochs: to which we may add 20,000 years to cover the interstadial stages of post-Würmian times.

For various reasons it is more difficult to estimate the duration of the cold or glacial epochs. The extent of their respective moraines and fluvio-glacial gravels lead to the inference that the Mindel and Riss epochs were longer than the Würm epoch. But there are so many other considerations to be kept in view that such inferences cannot be advanced with any confidence. It is further quite impossible to say whether the duration of the several glacial epochs bore any relation to that of the interglacial epochs. Judging from the amount of glacial erosion, however, we can hardly doubt that the duration of the several glacial and stadial epochs combined must have largely exceeded 200,000 years. That number is of course a mere guess, and probably, as I have said, much under the truth. It is only a third, indeed, of the time estimated by Dr Penck for two interglacial epochs. But taking his figures and adding those I have just given, we have a minimum period of 620,000 years for the duration of Pleistocene times.

Quite recently Professor Penck has expressed the

opinion that the Glacial period with all its climatic changes may have extended over half a million to a million years, and as the Chellean stage dates back to at least the middle of the period, this would give somewhere between 250,000 and 500,000 years for the antiquity of man in Europe. But if, as recent discoveries would seem to indicate, man was an occupant of our Continent during the First Interglacial epoch, if not in still earlier times, we may be compelled greatly to increase our estimate of his antiquity.

I have referred specially to Penck's opinion for the simple reason that it is based upon a profound knowledge of the geological data, which are best displayed in a mountainous region like the Alps, where all the evidence of glacial and fluviatile erosion and accumulation can be studied more satisfactorily than elsewhere. I might have cited other computations of the duration of the Pleistocene period, most of which are under Penck's estimate—the amount of time allowed by them varying from 100,000 to 400,000 years. But as these computations are based on the assumption that the Pleistocene occupied only one-thirtieth, or it may have been one-tenth, of the time required for the formation of all the preceding Tertiary systems, they are obviously unreliable. It is no doubt true that Pleistocene time was merely a fraction of the extensive period covered by Tertiary history, which has been variously estimated as equal to 3,000,000 or even 6,000,000 years, and it may quite well have been longer. The absolute

duration of the Tertiary is in short quite conjectural, and therefore any estimate of the fraction of that period required for Pleistocene history cannot be seriously considered.

In concluding I would again remind you of what was said in my first lecture as to geological measurements of time. In the very nature of things they cannot be definite. Penck's estimate makes no pretension to be other than a rough approximation; but as it is based on actual observation of the amount of geological work accomplished during the Pleistocene it is on that account justifiable, and undoubtedly helps us to realise how greatly extended are the periods of time embraced by glacial history.

So far removed from us are early Pleistocene times that our sympathetic interest in the life of Palæolithic man cannot but be faint. And yet he was very human: doubtless at the outset of his career a beastially selfish and merciless savage, but gradually developing finer traits with the passing of the ages. It is not without emotion that we look at the beautiful art-work of the Magdalenian reindeer hunter. And when we remember the conditions under which he lived—exposed to a severe climate and the attacks of many formidable wild beasts, his home a dark cave or rude rock-shelter—we may well be astonished at his attainments as an engraver, a sculptor, and an animal painter. With the simplest of tools and appliances his best efforts rival, if they do not sometimes excel, those of our modern art-schools, and

must ever be a marvel to critics who may have nourished the belief that such attainments are only possible in a civilised community.

Neither can we contemplate without a certain reverential awe the profound antiquity of our race, nor cease to wonder at the preservation of the humble records of Palæolithic man. When we think of the countless multitudes of unknown nameless folk—of the innumerable generations of primitive peoples passed into oblivion ages before the dawn of the earliest civilisations known to history—we recall the words of the grand old physician of Norwich: "The number of the dead long exceedeth all that shall live. The night of time far surpasseth the day, and who knoweth when was the Equinox." And yet of all those primitive peoples, those vanished races, we should have remained absolutely ignorant but for the endurance of their lost and discarded relics. "Time which antiquates antiquities, and hath an art to make dust of all things, hath yet spared these minor monuments. In vain we hope to be known by open and visible conservatories, when to be unknown was the means of their preservation, and obscurity their protection."

NOTES

1. Pre-Palæolithic Artifacts.

Sir E. Ray Lancaster has since described and figured the supposed artifacts discovered by Mr Moir in the Pliocene of East Anglia (*Philosophical Transactions*, 1912, Ser. B., p. 283). See papers by Mr Moir in *Proceedings of the Prehistoric Society of East Anglia*, vol. i., part 1; *Bedrock*, 1913, p. 165. The same author has recorded the occurrence of flint implements from the glacial deposits of Suffolk (*Proc. Prehist. Soc. East Anglia*, vol. i., part 3; *Bedrock*, 1914, p. 490). This last paper gives good illustrations of the several kinds of "pre-Palæolithic implements" discovered by Mr Moir. His opinion as to their human origin has not met with general acceptance, and archæologists will doubtless engage in much discussion before the matter is definitely settled.

2. Southern and Temperate Faunas and Floras.

The short account of these is abridged from the descriptions given in *Prehistoric Europe*, Chaps. II. and III., where references to original sources of information will be found.

3. Tundra and Steppe Faunas and Floras.

For my sketch of tundras and steppes I have made free use of a paper "On the Tundras and Steppes of Prehistoric Europe" (*Scottish Geographical Magazine*, vol. xiv.), the details in which are derived in large measure from Professor Nehring's well-known work, *Ueber Tundren und Steppen der Jetzt und Vorzeit*, 1890.

4. Culture-Stages of Pleistocene Times.

One of the best introductions to the study of prehistoric relics is MM. G. and A. de Mortillet's *Musée Prehistorique*, 1903. This

work contains a large series of plates illustrative of the artifacts characteristic of the successive culture-stages. The English reader may refer to Dr Munro's *Palæolithic Man and Terramara Settlements in Europe*, 1912, Chap. II., for a summary account of these culture-stages, and to Chaps. V.-VIII. and Chap. X. of the same work for descriptions of the several types of "fossil man" discovered in our Continent. See also Dr Duckworth's excellent little treatise, *Prehistoric Man*, 1912. The Piltdown skull mentioned on page 47 is described in a paper by Mr C. Dawson and Dr A. Smith Woodward (*Quart. Journ. Geol. Soc.*, 1913, p. 117). Unfortunately, its precise geological horizon has not been determined.

5. English Caves.

Kent's Cavern was explored between 1860 and 1880 under the superintendence of Mr Pengelly. The results of his research are published in the yearly *Reports of the British Association*. An interesting sketch of the exploration is given by him in a lecture entitled "Kent's Cavern" (*Science Lectures for the People*, 1872); see also a pamphlet entitled *The Ancient Cave-men of Devonshire*, published at Torquay. An account of the earlier investigations by MacEnery and others will be found in *Transactions of the Devonshire Association* for 1868, 1869.

Brixham Cave.—The exploration of this cave was conducted by a committee of the Geological Society, and under the superintendence of Mr Pengelly (*Philosophical Transactions*, 1873, p. 471).

Many other English caves have been explored, among which may be mentioned Kirkdale Cavern, in Yorkshire, described long ago by Dr Buckland as a hyæna den (*Reliquiæ Diluvianæ*, 1823); Victoria cave, near Settle, Yorkshire, explored chiefly by Mr R. H. Tiddeman (*Brit. Assoc. Reports*, 1874, 1875; *Geol. Mag.*, 1873, p. 11); Cresswell Crags Caves, Derbyshire, explored by Rev. J. Magens Mello (*Quart. Journ. Geol. Soc.*, vols. xxxi.-xxxiii., and vol. xxxv.), and certain caves in the Vale of Clwyd, described by Dr Hicks (*Quart. Journ. Geol. Soc.*, vol. xlii., p. 3; *Geol. Mag.*, 1885, p. 510). For references to other caves see H. B. Woodward's *The Geology of England and Wales*, p. 541.

The most recent contribution to our knowledge of British caves is an interesting and instructive lecture by Professor Sollas: "Paviland Cave: an Aurignacian Station in Wales" (*Journ. Royal Anthrop. Institute*, vol. xliii., 1913). In my second Lecture (p. 64)

I have stated that no indubitable trace of the Aurignacian stage of culture has hitherto been recognised in Britain. Professor Sollas has now put it beyond doubt that Aurignacian man flourished here just as on the Continent.

6. Caves of the Continent.

The literature of cave-exploration on the Continent is very abundant, but the reader will find full and instructive summaries of the evidence in Professor Obermaier's recently published work, "Der Mensch der Vorzeit," *Der Mensch aller Zeiten*, vol. i., 1912-13. Another recent work, *Die diluviale Vorzeit Deutschlands*, 1912, by Dr R. R. Schmidt, gives an admirable and copiously illustrated description of the caves of Germany. Of the many important works dealing with special caves mention may be made of the splendid monograph by MM. E. Cartailhac and H. Breuil, *La Caverne d'Altamira*, 1906, the admirably executed figures and plates of which exhibit the artistic attainments of Magdalenian man in mural drawing and painting. Another magnificent monograph in course of publication, *Les Grottes de Grimaldi*, is devoted to a description of the exploration of those caves, to three of which I have made some reference in the text. Both of these elaborate works we owe to the munificence of Prince Albert I. of Monaco.

7. Palæolithic Floors.

The phenomena of these interesting "floors" are fully described by Mr Worthington Smith in *Man, the Primeval Savage*, 1894.

8. Stones "on End" in Pleistocene River-Gravels.

For Mr Darwin's explanation of these see *Life and Letters of C. Darwin*, vol. iii., p. 213.

9. Over-deepening of Valleys by Glacial Erosion.

The amount of over-deepening attributed to the action of great valley-glaciers may appear almost incredible. But that glaciers are powerful agents of erosion must be admitted, and just for the same reason as streams and rivers are allowed to be so. If streams in time can cut deep gorges for hundreds of feet through hard rock, and rivers can excavate profound cañons like those of the Colorado,

why should glaciers be incapable of deepening their beds? Surely a massive glacier flowing for a prolonged period must inevitably deepen its valley in proportion to its size and its duration. When we realise that a glacial epoch embraced many thousands of years, and that such epochs returned again and again during the Pleistocene period, the over-deepening of Alpine valleys and Norwegian fiords will cease to surprise us.

10. Thickness of Pleistocene Glaciers.

In estimating the probable thickness attained by these glaciers, geologists usually measure from the bottom of a valley to the upper limits reached by glaciation, which may often yield a sufficiently reliable result. It is obvious, however, that allowance should be made for glacial erosion. In the case of over-deepened mountain valleys and fiords, for instance, the apparent thickness of the ice as indicated by the upper limits of glaciation is probably, as a rule, considerably in excess of the true thickness, for the surface of a glacier must be gradually lowered as the valley is deepened by erosion.

11. Nomenclature of Glacial and Interglacial Epochs.

Some years ago (*Journ. of Geology*, vol. iii., p. 241) I suggested tentative names for the several glacial and interglacial stages of the Pleistocene. At that time the succession of the several glacial epochs had been more or less definitely ascertained, but the precise position of many of the interglacial deposits of our Continent was still doubtful. For instance, the well-known interglacial deposits of Switzerland were then supposed to belong to the Second Interglacial, and I therefore proposed to designate that epoch the "Helvetian." But the careful researches of MM. Penck and Bruckner have proved these particular interglacial beds to be on the horizon of the Third Interglacial stage, and the term "Helvetian" is therefore no longer appropriate. I now venture to suggest *Tyrolian* as a better designation for the Second Interglacial epoch, after the famous plant-bearing breccias of Hotting, near Innsbruck (Tyrol), described by Professor Penck and assigned by him to that epoch. The Third Interglacial, formerly termed by me "Neudeckian," I have now renamed *Durntenian*, in recognition of the fact that the deposits of that stage are best represented by the well-known lignite-beds of Durnten,

etc., in Switzerland. The only other change I would suggest is the substitution of the more euphonious *Polonian* for "Polandian," as a name for the Third Glacial epoch.

12. Durntenian or Third Interglacial Epoch.

Amongst the interglacial formations which have been assigned to this stage are those of Krapina and the fluvio-lacustrine deposits of Taubach, in Saxe Weimar. At Krapina remains of the broad-nosed rhinoceros abounded, and were associated with those of members of the temperate group of mammals, while tundra and steppe faunas had no representatives. The southern and temperate group occurs on two horizons—namely, the Tyrolian or Second Interglacial, and the Durntenian or Third Interglacial stage. So far, then, as the evidence of its fauna is concerned the Krapina rock-shelter might belong to either of these interglacial horizons. The accompanying artifacts, it would seem, are indeterminate: they may be either Chellean or Mousterian. The human remains, however, are unquestionably those of Neandertal man, and since all the skeletons of that race hitherto discovered are of Mousterian age, and never occur along with Chellean implements, there can be little doubt that the Krapina station belongs to the Durntenian or Third Interglacial stage.

The Taubach deposits overlie gravel-beds containing erratics of northern derivation, and are capped by loess, so that their interglacial character is obvious. The gravel-beds are of fluvio-glacial origin, deposited at a time when a great northern ice-sheet extended far south in Germany. The *mer de glace* in question was, in all probability, that of the Third Glacial or Polonian stage, and, if so, the Taubach beds with their southern fauna and relics and remains of Palæolithic man must be of Durntenian age. On the other hand, the underlying fluvio-glacial gravels may yet prove to be those of the Saxonian epoch, in which case the Taubach beds would take their place in the Tyrolian or Second Interglacial stage. Unfortunately, the artifacts associated with the southern fauna at Taubach are apparently as indeterminate as those of Krapina, and cannot be certainly assigned either to a Mousterian or a Chellean horizon.

It is interesting to note that M. Commont has recently discovered Mousterian artifacts associated with the southern or "warm" fauna in the river-drifts of the Somme Valley, at Montières-lès-Amiens.

The forms include straight-tusked elephant, hippopotamus, and broad-nosed rhinoceros. (See "Moustérien a faune chaude dans la vallée de la Somme," etc., *Congrès Internat. d'Anthropologie*, etc., Geneva, 1912, t. i., p. 291.) M. Commont thinks that the deposits in question belong to the end of the Riss-Wurm or Third Interglacial stage. But that is highly improbable—they almost certainly must be assigned to the culmination of that genial epoch. Unfortunately, M. Commont, following Professor Boule, has crowded all the Older Palæolithic culture-stages into the Third Interglacial, and he is doubtless embarrassed by the occurrence of the warm fauna on two horizons in one and the same interglacial epoch. But the fauna in question is not confined to one stage—it characterises both Second and Third Interglacial stages. M. Commont's important discovery is quite in keeping with the appearance in the Thames valley of the Mousterian "floor," the plant-remains of which clearly indicate temperate conditions; and furthermore it strongly supports Professor Penck's contention that Mousterian man was contemporaneous in middle Europe with the tundra fauna at one time and with the southern fauna at another.

13. Interstadial Phases of the Alpine Glacial Succession.

The climatic oscillations of post-Wurmian times were obviously of inconsiderable extent when contrasted with those of the earlier Pleistocene, and the climatic changes indicated by the corresponding stages of the post-Mecklenburgian in Britain were likewise less important than those which had preceded them. The earlier glacial and interglacial phases were not only more prolonged, but more strongly contrasted than the post-Mecklenburgian stages. Nevertheless, the climatic oscillations of Forestian and Turbarian times were of very considerable amplitude, and must have been experienced over a large part of our Continent. They were neither unimportant nor merely local phenomena, and there is no reason, therefore, why they should not be included in the great glacial cycle and described as glacial and interglacial. When the conditions that obtained in Turbarian times are contrasted with those of our day, this contention must appear to be well founded. The arctic-alpine flora occurs in Scotland at and above a height of 2000 feet; in Turbarian times it descended to the sea-level. Moreover, during the Lower Turbarian stage considerable glaciers reached

the sea in our West Highlands, while in the later Turbarian stage many high-level corries would seem to have been occupied by small glaciers. Surely such conditions contrast strongly with the present, and still more strongly with the conditions of Forestian times, when our forests extended to a height of 3500 feet, that is, some 1500 feet above the present limit of tree-growth.

The formations of late Pleistocene age have not been so assiduously studied in the low grounds of middle Europe as they will yet be. It can hardly be doubted, however, that climatic oscillations so pronounced as those to which our raised beaches and peat-mosses testify will eventually be found to have affected a large part of the Continent. The stadial and interstadial stages of the Alpine lands have been cited as the equivalents in time of our post-Mecklenburgian stages, but even stronger evidence of the amplitude of the later climatic oscillations has recently been obtained from the same region. Dr Hans Schreiber, who has of late years carried on researches in the peat-bogs distributed along the northern border of the East Alps, has come to the conclusion that this tract in post-Wurmian times experienced climatic changes, comparable in all respects to those that marked the closing phases of the glacial cycle in Scotland. He describes a succession of five stages which he parallels with the Scottish series and the corresponding stadial and interstadial stages of Penck and Bruckner. In his opinion the Buhl-Gschnitz interstadial stage (= Lower Forestian) was very warm and dry—warmer and drier, in fact, than the present—so that the snow-line at that time must have been 100 metres higher than now (H. Schreiber, "Vergletscherung und Moorbildung in Salzburg," etc., *Verlag des Deutsch-osterreichischen Moorvereins*). Similar results have been obtained by V. Zailer from researches in the peat occurring within the basin of the river Enn. ("Die Enstehungs-geschichte der Moore," etc., *Zeitschrift fur Moorkultur und Torfverwertung*, 1910. An outline of Schreiber's and Zailer's work is given by Professor Bruckner in *Zeitschrift fur Gletscherkunde*, Bd. vii., p. 334.) According to Penck and Bruckner the snow-line of the Buhl stadium stood 900 metres lower than now, while Schreiber believes it rose in the succeeding interstadial epoch 100 metres above its present level. A rise of the snow-line of 3250 feet or thereabout is surely indicative of a very considerable change of climate, and we should be justified in distinguishing as *interglacial* the epoch during which it occurred.

14. The Azilian Stage and the supposed "Hiatus" between Palæolithic and Neolithic Epochs.

Archæologists usually assign to the Azilian stage certain minute flint artifacts that show peculiar geometrical forms, as rhomboid, trapezoid, triangular, segment of a circle, etc. From the abundance of these microlithic implements at Fère-en-Tardenois (Aisne), accumulations characterised by their presence have been termed *Tardenoisian*. Such Tardenoisian artifacts have been recorded from a number of Azilian stations and also, it may be added, from various Neolithic accumulations in England.

According to archæologists, the Azilian or Azilian-Tardenoisian culture-stage bridges over the supposed break in the continuity of the human occupation of our Continent. This confident opinion, however, is hardly warranted by the evidence. So far as that goes, it proves that towards the close of Magdalenian times climatic conditions were gradually changing, and it seems to indicate that in southern Europe no long interval occurred between the exit of Palæolithic man and the entrance of his Neolithic successor. The discoveries at Mas d'Azil and elsewhere, therefore, would appear to have left the question of the "hiatus" just where it was over thirty years ago. At that time M. Piette had recently examined the cave of Gourdan in the Pyrenees, and described certain appearances which led him to infer that the Palæolithic and Neolithic races had come into contact; and the results obtained by MM. Lartet and Duparc in the rock-shelter at Sorde seemed to favour the same conclusion. The researches and conjectures of M. de Quatrefages and other anthropologists likewise tended to support the view that no "hiatus" existed. Commenting on the evidence available at the time, I ventured in 1881 to write as follows: "It is quite clear that a wide interval separates the Palæolithic and the Neolithic ages everywhere in central and north-western Europe; but it is less certain that this interval was as prolonged in the south of France. Possibly, therefore, the Palæolithic and the Neolithic races may have commingled in Périgord at a time when the reindeer was still living, but in greatly diminished numbers in the valleys of the Pyrenees. But there is nothing to show that any of the Palæolithic tribes were 'carried away in the pursuit of the reindeer' to its present home in Scandinavia. A prolonged period intervened between the close of the Ice Age (*i.e.*, the Mecklenburgian or

Wurmian stage) and the reappearance of Man in central and north-western Europe" (*Prehistoric Europe*, p. 553). That statement, I believe, still sums up all that is certainly known as to the passage from the Old Stone to the New Stone period.

The bone artifacts belonging to the so-called "transition-beds" at Mas d'Azil are supposed to be decadent Palæolithic, but the awls, pointers, and spatulæ in question are all very simple forms, and might quite well be of Neolithic age. They are indefinite in character and not distinctively Magdalenian. No other evidence supplied by the "transition-beds" is clearly suggestive of pre-Neolithic conditions; on the contrary, it seems rather to point in the other direction. The stag-horn harpoons are certainly Neolithic types, for exactly similar implements occur in the 25- to 30-foot beach in Scotland; while the water-worn stones, with their mysterious markings, and the heaps of snail shells, together with the fragments of pottery obtained in the Arisian "transition-bed," are all strongly suggestive of a Neolithic horizon. Moreover, it must be remembered that the Azilian is separated from the Magdalenian beds below by four feet of river alluvia. This need not indicate a long interval, but it certainly implies a "break" of some kind and not a gradual transition. Again, we note that not a single trace of the reindeer or any of its arctic-alpine associates has hitherto been met with in the Azilian or Azilian-Tardenoisian either of France or Germany.

It has been long known to geologists and archæologists that in early Neolithic times a primitive people, living chiefly on shell-fish and the produce of the chase, overspread wide regions in north-western Europe. Their "kitchen-middens" are met with again and again in Britain in connection with ancient raised beaches; and similar accumulations occur in Finland, Denmark, and elsewhere. In Scotland the oldest of these prehistoric "middens" belong to our 45- to 50-foot beach (*i.e.*, Lower Turbarian), while the youngest are associated with the much later 25- to 30-foot beach (*i.e.*, Upper Turbarian). If, as some archæologists suppose, the Oban deposits are Azilian, then that stage must be long posterior in date to the Magdalenian, and cannot possibly represent the transition from Palæolithic to Neolithic times. It may quite well be that Neolithic man appeared in southern Europe before Palæolithic man had vanished from the Pyrenean region, and the two races may possibly have there come in contact. But such evidence as we have goes to

show that the older race had departed from central and north-west Europe long before the advent of Neolithic man in those latitudes. The "hiatus" recognised by geologists more than thirty years ago has not yet been bridged over.

15. River-drifts of the Somme Valley.

Quite recently M. Commont has recorded the occurrence of Aurignacian and Solutréan artifacts from the river-drifts of the Somme, so that the succession of culture-stages is even more complete than is stated in the text (see pp. 111-112). The artifacts in question have been obtained from the upper part of the "ergeron." It may be as well to mention here that M. Commont's sections of the drifts are much more detailed than I have represented them to be. Thus he has several sub-divisions of each of the "loams," and of the river-gravels and sands of the terraces. These it was not necessary for me to particularise, as only the general succession of the culture-stages was required for my purpose. His "Strepyan," therefore, is included by me in the Chellean, and his sub-division of the later culture-stages into "Lower" and "Upper" Acheulian, Mousterian, etc., have been necessarily ignored. (See V. Commont, "Chronologie et stratigraphie des industrie protohistoriques," etc., *Congrès Internat. d'Anthropologie*, etc., *Compte Rendu de la XIVe Session*, 1912, t. i., p. 239.)

16. Maps of Europe during Glacial and Interglacial Epochs.

Map A shows the areas subjected to glaciation during the Saxonian or Second Glacial epoch. The limits reached by the great northern *mer de glace* have been fairly well ascertained, so far as the land-area is concerned. How far out into the Atlantic the ice flowed can only be conjectured, but it is not likely to have extended much beyond the 100-fms. line.

Map B represents the greatest extension of land which is inferred to have taken place in interglacial times. It is designed chiefly to indicate the position of the land-bridges which formerly united Europe and Africa, and the probable geographical conditions in the north-west when the British Islands formed part of the Continent. The map, it will be understood, does not represent the distribution of land and sea during any particular interglacial stage.

Elevation of the land seems to have characterised each interglacial phase, but the extent and amount of elevation would seem to have varied. Probably the widest extension of the land took place during the Second (Tyrolian) and Third (Durntenian) Interglacial epochs. But the British area was certainly continental in Lower Forestian times.

Map C shows the probable limits reached by the ice of the Third (Polonian) Glacial epoch in the British area, in Holland, north Germany, and west Poland. But the boundary line through Poland and Russia to the Arctic Ocean is largely conjectural, as indicated by the query marks. The limits given for the ice-sheet in the Atlantic are equally conjectural.

Map D.—The area occupied by the northern ice-sheet of the Fourth (Mecklenburgian) Glacial epoch was considerably less extensive. Its limits are indicated by numerous lines of terminal moraines—the map having been compiled chiefly from papers by the late Dr Ussing and Professor Wahnschaffe, which embody the views of many eminent geologists in Scandinavia, Germany, and Finland.

INDEX

PRINTED BY OLIVER AND BOYD, EDINBURGH

D. VAN NOSTRAND COMPANY

25 PARK PLACE

New York

SHORT-TITLE CATALOG

OF

Publications and Importations

OF

SCIENTIFIC AND ENGINEERING BOOKS

This list includes the technical publications of the following English publishers:

SCOTT, GREENWOOD & CO.
CONSTABLE & COMPANY, Ltd. TECHNICAL PUBLISHING CO.
ELECTRICIAN PRINTING & PUBLISHING CO.

for whom D. Van Nostrand Company are American agents.

SHORT-TITLE CATALOG

OF THE

Publications and Importations

OF

D. VAN NOSTRAND COMPANY

25 PARK PLACE, N. Y.

Prices marked with an asterisk (*) are NET.
All bindings are in cloth unless otherwise noted.

Abbott, A. V. The Electrical Transmission of Energy.	8vo,	*$5 00
—— A Treatise on Fuel. (Science Series No. 9.)	16mo,	0 50
—— Testing Machines. (Science Series No. 74.)	16mo,	0 50
Adam, P. Practical Bookbinding. Trans. by T. E. Maw	12mo,	*2 50
Adams, H. Theory and Practice in Designing	8vo,	*2 50
Adams, H. C. Sewage of Sea Coast Towns	8vo	*2 00
Adams, J. W. Sewers and Drains for Populous Districts	8vo,	2 50
Addyman, F. T. Practical X-Ray Work	8vo,	*4 00
Adler, A. A. Theory of Engineering Drawing.	8vo,	*2 00
—— Principles of Parallel Projecting-line Drawing	8vo,	*1 00
Aikman, C. M. Manures and the Principles of Manuring.	8vo,	2 50
Aitken, W. Manual of the Telephone.	8vo,	*8 00
d'Albe, E. E. F., Contemporary Chemistry	12mo,	*1 25
Alexander, J. H. Elementary Electrical Engineering.	12mo,	2 00
Allan, W. Strength of Beams Under Transverse Loads. (Science Series No. 19.)	16mo,	0 50
—— Theory of Arches. (Science Series No. 11.)	16mo,	
Allen, H. Modern Power Gas Producer Practice and Applications	12mo,	*2 50
—— Gas and Oil Engines	8vo,	*4 50
Anderson, F. A. Boiler Feed Water	8vo,	*2 50
Anderson, Capt. G. L. Handbook for the Use of Electricians	8vo,	3 00
Anderson, J. W. Prospector's Handbook	12mo,	1 50
Andés, L. Vegetable Fats and Oils	8vo,	*4 00
—— Animal Fats and Oils. Trans. by C. Salter	8vo,	*4 00
—— Drying Oils, Boiled Oil, and Solid and Liquid Driers	8vo,	*5 00
—— Iron Corrosion, Anti-fouling and Anti-corrosive Paints. Trans. by C. Salter	8vo,	*4 00
Andés, L. Oil Colors, and Printers' Ink. Trans. by A. Morris and H. Robson	8vo,	*2 50
Andés, L. Treatment of Paper for Special Purposes. Trans. by C. Salter.		

Andrews, E. S. Reinforced Concrete Construction.............12mo,	*1 25
—— Theory and Design of Structures 8vo,	*3 50
—— Further Problems in the Theory and Design of Structures 8vo,	*2 50
Annual Reports on the Progress of Chemistry. Nine Volumes now ready. Vol. I. 1904, Vol. IX, 1912. . . . 8vo, each,	2 00
Argand, M. Imaginary Quantities. Translated from the French by A. S. Hardy. (Science Series No. 52.)..... . . 16mo,	0 50
Armstrong, R., and Idell, F. E. Chimneys for Furnaces and Steam Boilers. (Science Series No. 1.)........ 16mo,	0 50
Arnold, E. Armature Windings of Direct-Current Dynamos. Trans. by F. B. DeGress 8vo,	*2 00
Asch, W., and Asch, D. The Silicates in Chemistry and Commerce 8vo,	*6 00
Ashe, S. W., and Keiley, J. D. Electric Railways. Theoretically and Practically Treated. Vol. I. Rolling Stock 12mo,	*2 50
Ashe, S. W. Electric Railways. Vol. II. Engineering Preliminaries and Direct Current Sub-Stations . 12mo,	*2 50
—— Electricity: Experimentally and Practically Applied 12mo,	*2 00
Ashley, R. H. Chemical Calculations (*In Press*)	
Atkins, W. Common Battery Telephony Simplified 12mo,	*1 25
Atkinson, A. A. Electrical and Magnetic Calculations 8vo,	*1 50
Atkinson, J. J. Friction of Air in Mines. (Science Series No. 14.) .16mo,	0 50
Atkinson, J. J., and Williams, Jr., E. H. Gases Met with in Coal Mines. (Science Series No. 13.) . . . 16mo,	0 50
Atkinson, P. The Elements of Electric Lighting. 12mo,	1 50
—— The Elements of Dynamic Electricity and Magnetism 12mo,	2 00
—— Power Transmitted by Electricity . . 12mo,	2 00
Auchincloss, W. S. Link and Valve Motions Simplified 8vo,	*1 50
Ayrton, H. The Electric Arc . . 8vo,	*5 00
Bacon, F. W. Treatise on the Richards Steam-Engine Indicator 12mo,	1 00
Bailes, G. M. Modern Mining Practice. Five Volumes . 8vo, each,	3 50
Bailey, R. D. The Brewers' Analyst. . 8vo,	*5 00
Baker, A. L. Quaternions. 8vo,	*1 25
—— Thick-Lens Optics .. . 12mo,	*1 50
Baker, Benj. Pressure of Earthwork. (Science Series No. 56.)...16mo,	
Baker, I. O. Levelling. (Science Series No. 91.).... 16mo,	0 50
Baker, M. N. Potable Water. (Science Series No. 61.)..... 16mo,	0 50
—— Sewerage and Sewage Purification. (Science Series No. 18.)..16mo,	0 50
Baker, T. T. Telegraphic Transmission of Photographs 12mo,	*1 25
Bale, G. R. Modern Iron Foundry Practice. Two Volumes. 12mo.	
Vol. I. Foundry Equipment, Materials Used	*2 50
Vol. II. Machine Moulding and Moulding Machines .	*1 50
Bale, M. P. Pumps and Pumping. 12mo,	1 50
Ball, J. W. Concrete Structures in Railways . . 8vo,	*2 50
Ball, R. S. Popular Guide to the Heavens 8vo,	*4 50
—— Natural Sources of Power. (Westminster Series.) .. 8vo,	*2 00
Ball, W. V. Law Affecting Engineers 8vo,	*3 50
Bankson, Lloyd. Slide Valve Diagrams. (Science Series No. 108.).16mo,	0 50
Barba, J. Use of Steel for Constructive Purposes .. 12mo,	1 00
Barham, G. B. Development of the Incandescent Electric Lamp 8vo,	*2 00

Barker, A. F. Textiles and Their Manufacture. (Westminster Series.) 8vo, 2 00

Barker, A. F., and Midgley, E. Analysis of Textile Fabrics ... 8vo, 3 00

Barker, A. H. Graphic Methods of Engine Design. .... .12mo, *1 50

—— Heating and Ventilation 4to, *8 00

Barnard, J. H. The Naval Militiaman's Guide 16mo, leather 1 00

Barnard, Major J. G. Rotary Motion. (Science Series No. 90.)....16mo, 0 50

Barrus, G. H. Boiler Tests 8vo, *3 00

—— Engine Tests 8vo, *4 00

The above two purchased together *6 00

Barwise, S. The Purification of Sewage 12mo, 3 50

Baterden, J. R. Timber. (Westminster Series.) . . 8vo, *2 00

Bates, E. L., and Charlesworth, F. Practical Mathematics 12mo,

Part I. Preliminary and Elementary Course................. .. *1 50

Part II. Advanced Course *1 50

—— Practical Mathematics 12mo, *1 50

—— Practical Geometry and Graphics 12mo, *2 00

Beadle, C. Chapters on Papermaking. Five Volumes 12mo, each, *2 00

Beaumont, R. Color in Woven Design. . 8vo, *6 00

—— Finishing of Textile Fabrics. 8vo, *4 00

Beaumont, W. W. The Steam-Engine Indicator 8vo, 2 50

Bechhold, H. Colloids in Biology and Medicine. Trans. by J. G. Bullowa . . . . (*In Press.*)

Beckwith, A. Pottery . 8vo, paper, 0 60

Bedell, F., and Pierce, C. A. Direct and Alternating Current Manual. 8vo, *2 00

Beech, F. Dyeing of Cotton Fabrics. 8vo, *3 00

—— Dyeing of Woolen Fabrics. .. 8vo, *3 50

Begtrup, J. The Slide Valve .. 8vo, *2 00

Beggs, G. E. Stresses in Railway Girders and Bridges ....(*In Press.*)

Bender, C. E. Continuous Bridges. (Science Series No. 26.)... 16mo, 0 50

—— Proportions of Piers used in Bridges. (Science Series No. 4.) 16mo, 0 50

Bennett, H. G. The Manufacture of Leather 8vo, *4 50

—— Leather Trades (Outlines of Industrial Chemistry). 8vo..(*In Press.*)

Bernthsen, A. A Text-book of Organic Chemistry. Trans. by G. M'Gowan....... .. .. 12mo, *2 50

Berry, W. J. Differential Equations of the First Species. 12mo. (*In Preparation.*)

Bersch, J. Manufacture of Mineral and Lake Pigments. Trans. by A. C. Wright 8vo, *5 00

Bertin, L. E. Marine Boilers. Trans. by L. S. Robertson........ 8vo, 5 00

Beveridge, J. Papermaker's Pocket Book.. . . .. 12mo, *4 00

Binnie, Sir A. Rainfall Reservoirs and Water Supply.......... 8vo, *3 00

Binns, C. F. Ceramic Technology........ . .. . 8vo, *5 00

—— Manual of Practical Potting 8vo, *7 50

—— The Potter's Craft 12mo, *2 00

Birchmore, W. H. Interpretation of Gas Analysis............12mo, *1 25

Blaine, R. G. The Calculus and Its Applications. 12mo, *1 50

Blake, W. H. Brewers' Vade Mecum 8vo, *4 00

Blasdale, W. C. Quantitative Chemical Analysis... 12mo. (*In Press.*)

Bloch, L. Science of Illumination. Trans. by W. C. Clinton	8vo,	*2 50
Blok, A. Illumination and Artificial Lighting	12mo,	1 25
Blücher, H. Modern Industrial Chemistry. Trans. by J. P. Millington.	8vo,	*7 50
Blyth, A. W. Foods: Their Composition and Analysis	8vo,	7 50
—— Poisons: Their Effects and Detection	8vo,	7 50
Böckmann, F. Celluloid	12mo,	*2 50
Bodmer, G. R. Hydraulic Motors and Turbines	12mo,	5 00
Boileau, J. T. Traverse Tables	8vo,	5 00
Bonney, G. E. The Electro-platers' Handbook	12mo,	1 20
Booth, N. Guide to the Ring-spinning Frame	12mo,	*1 25
Booth, W. H. Water Softening and Treatment	8vo,	*2 50
—— Superheaters and Superheating and Their Control	8vo,	*1 50
Bottcher, A. Cranes: Their Construction, Mechanical Equipment and Working. Trans. by A. Tolhausen	4to,	*10 00
Bottler, M. Modern Bleaching Agents. Trans. by C. Salter	12mo,	*2 50
Bottone, S. R. Magnetos for Automobilists	12mo,	*1 00
Boulton, S. B. Preservation of Timber. (Science Series No. 82.)	16mo,	0 50
Bourcart, E. Insecticides, Fungicides and Weedkillers	8vo,	*4 50
Bourgougnon, A. Physical Problems. (Science Series No. 113.)	16mo,	0 50
Bourry, E. Treatise on Ceramic Industries. Trans. by A. B. Searle.	8vo,	*5 00
Bow, R. H. A Treatise on Bracing	8vo,	1 50
Bowie, A. J., Jr. A Practical Treatise on Hydraulic Mining	8vo,	5 00
Bowker, W. R. Dynamo, Motor and Switchboard Circuits	8vo,	*2 50
Bowles, O. Tables of Common Rocks. (Science Series No. 125.)	16mo,	0 50
Bowser, E. A. Elementary Treatise on Analytic Geometry	12mo,	1 75
—— Elementary Treatise on the Differential and Integral Calculus	12mo,	2 25
—— Elementary Treatise on Analytic Mechanics	12mo,	3 00
—— Elementary Treatise on Hydro-mechanics	12mo,	2 50
—— A Treatise on Roofs and Bridges	12mo,	*2 25
Boycott, G. W. M. Compressed Air Work and Diving	8vo,	*4.00
Bragg, E. M. Marine Engine Design.	12mo,	*2 00
Brainard, F. R. The Sextant. (Science Series No. 101.)	16mo,	
Brassey's Naval Annual for 1911.	8vo,	*6 00
Brew, W. Three-Phase Transmission	8vo,	*2 00
Briggs, R., and Wolff, A. R. Steam-Heating. (Science Series No. 67.)	16mo,	0 50
Bright, C. The Life Story of Sir Charles Tilson Bright	8vo,	*4 50
Brislee, T. J. Introduction to the Study of Fuel. (Outlines of Industrial Chemistry.)	8vo,	*3 00
Broadfoot, S. K. Motors, Secondary Batteries. (Installation Manuals Series.)	12mo,	*0 75
Broughton, H. H. Electric Cranes and Hoists		*9 00
Brown, G. Healthy Foundations. (Science Series No. 80.)	16mo,	0 50
Brown, H. Irrigation.	8vo,	*5 00
Brown, Wm. N. The Art of Enamelling on Metal	12mo,	*1 00
—— Handbook on Japanning and Enamelling	12mo,	*1 50
—— House Decorating and Painting	12mo,	*1 50
—— History of Decorative Art	12mo,	*1 25

Brown, Wm. N. Dipping, Burnishing, Lacquering and Bronzing Brass Ware. 12mo, *1 00
—— Workshop Wrinkles 8vo, *1 00
Browne, C. L. Fitting and Erecting of Engines . . 8vo, *1 50
Browne, R. E. Water Meters. (Science Series No. 81.) 16mo, 0 50
Bruce, E. M. Pure Food Tests 12mo, *1 25
Bruhns, Dr. New Manual of Logarithms 8vo, cloth, 2 00
half morocco, 2 50
Brunner, R. Manufacture of Lubricants, Shoe Polishes and Leather Dressings. Trans. by C. Salter . . 8vo, *3 00
Buel, R. H. Safety Valves. (Science Series No. 21.) 16mo, 0 50
Burns, D. Safety in Coal Mines. 12mo, *1 00
Burstall, F. W. Energy Diagram for Gas. With Text 8vo, 1 50
—— Diagram. Sold separately *1 00
Burt, W. A. Key to the Solar Compass 16mo, leather, 2 50
Burton, F. G. Engineering Estimates and Cost Accounts 12mo, *1 50
Buskett, E W. Fire Assaying . . 12mo, *1 25
Butler, H. J. Motor Bodies and Chassis 8vo, *2 50
Byers, H. G., and Knight, H. G. Notes on Qualitative Analysis 8vo, *1 50

Cain, W. Brief Course in the Calculus 12mo, *1 75
—— Elastic Arches. (Science Series No. 48.) 16mo, 0 50
—— Maximum Stresses. (Science Series No. 38.) 16mo, 0 50
—— Practical Designing Retaining of Walls. (Science Series No. 3.) 16mo, 0 50
—— Theory of Steel-concrete Arches and of Vaulted Structures. (Science Series No. 42.) 16mo, 0 50
—— Theory of Voussoir Arches. (Science Series No. 12.) 16mo, 0 50
—— Symbolic Algebra. (Science Series No. 73.) 16mo, 0 50
Campin, F. The Construction of Iron Roofs 8vo, 2 00
Carpenter, F. D. Geographical Surveying. (Science Series No. 37.). 16mo,
Carpenter, R. C., and Diederichs, H. Internal Combustion Engines. 8vo, *5 00
Carter, E. T. Motive Power and Gearing for Electrical Machinery 8vo, *5 00
Carter, H. A. Ramie (Rhea), China Grass 12mo, *2 00
Carter, H. R. Modern Flax, Hemp, and Jute Spinning 8vo, *3 00
Cary, E. R. Solution of Railroad Problems with the Slide Rule 16mo, *1 00
Cathcart, W. L. Machine Design. Part I. Fastenings 8vo, *3 00
Cathcart, W. L., and Chaffee, J. I. Elements of Graphic Statics 8vo, *3 00
—— Short Course in Graphics 12mo, 1 50
Caven, R. M., and Lander, G. D. Systematic Inorganic Chemistry 12mo, *2 00
Chalkley, A. P. Diesel Engines 8vo, *3 00
Chambers' Mathematical Tables 8vo, 1 75
Chambers, G. F. Astronomy . 16mo, *1 50
Charpentier, P. Timber 8vo, *6 00
Chatley, H. Principles and Designs of Aeroplanes. (Science Series No. 126). . . . 16mo, 0 50
—— How to Use Water Power 12mo, *1 00
—— Gyrostatic Balancing 8vo, *1 00
Child, C. D. Electric Arc 8vo, *2 00
Child, C. T. The How and Why of Electricity. 12mo, 1 00

Christian, M. Disinfection and Disinfectants. Trans. by Chas. Salter 12mo, 2 00
Christie, W. W. Boiler-waters, Scale, Corrosion, Foaming 8vo, *3 00
—— Chimney Design and Theory 8vo, *3 00
—— Furnace Draft. (Science Series No. 123.) 16mo, 0 50
—— Water: Its Purification and Use in the Industries 8vo, *2 00
Church's Laboratory Guide. Rewritten by Edward Kinch 8vo, *2 50
Clapperton, G. Practical Papermaking 8vo, 2 50
Clark, A. G. Motor Car Engineering.
Vol. I. Construction *3 00
Vol. II. Design (In Press.)
Clark, C. H. Marine Gas Engines 12mo, *1 50
Clark, D. K. Fuel: Its Combustion and Economy 12mo, 1 50
Clark, J. M. New System of Laying Out Railway Turnouts 12mo, 1 00
Clausen-Thue, W. A B C Telegraphic Code. Fourth Edition 12mo, *5 00
Fifth Edition 8vo, *7 00
—— The A 1 Telegraphic Code 8vo, *7 50
Clerk, D., and Idell, F. E. Theory of the Gas Engine. (Science Series No. 62.) 16mo, 0 50
Clevenger, S. R. Treatise on the Method of Government Surveying. 16mo, morocco, 2 50
Clouth, F. Rubber, Gutta-Percha, and Balata 8vo, *5 00
Cochran, J. Concrete and Reinforced Concrete Specifications 8vo, *2 50
—— Treatise on Cement Specifications 8vo, *1 00
Coffin, J. H. C. Navigation and Nautical Astronomy 12mo, *3 50
Colburn, Z., and Thurston, R. H. Steam Boiler Explosions. (Science Series No. 2.) 16mo, 0 50
Cole, R. S. Treatise on Photographic Optics 12mo, 1 50
Coles-Finch, W. Water, Its Origin and Use 8vo, *5 00
Collins, J. E. Useful Alloys and Memoranda for Goldsmiths, Jewelers. 16mo, 0 50
Collis, A. G. High and Low Tension Switch-Gear Design 8vo, 3 50
—— Switchgear. (Installation Manuals Series.) 12mo, *0 50
Constantine, E. Marine Engineers, Their Qualifications and Duties. 8vo, *2 00
Coombs, H. A. Gear Teeth. (Science Series No. 120.) 16mo, 0 50
Cooper, W. R. Primary Batteries 8vo, *4 00
—— "The Electrician" Primers 8vo, *5 00
Part I *1 50
Part II *2 50
Part III *2 00
Copperthwaite, W. C. Tunnel Shields 4to, *9 00
Corey, H. T. Water Supply Engineering 8vo (In Press.)
Corfield, W. H. Dwelling Houses. (Science Series No. 50.) 16mo, 0 50
—— Water and Water-Supply. (Science Series No. 17.) 16mo, 0 50
Cornwall, H. B. Manual of Blow-pipe Analysis 8vo, *2 50
Courtney, C. F. Masonry Dams 8vo, 3 50
Cowell, W. B. Pure Air, Ozone, and Water 12mo, *2 00
Craig, T. Motion of a Solid in a Fuel. (Science Series No. 49.) 16mo, 0 50
—— Wave and Vortex Motion. (Science Series No. 43.) 16mo, 0 50

Cramp, W. Continuous Current Machine Design 8vo, *2 50
Creedy, F. Single Phase Commutator Motors 8vo, *2 00
Crocker, F. B. Electric Lighting. Two Volumes. 8vo.
Vol. I. The Generating Plant 3 00
Vol. II. Distributing Systems and Lamps . . . . .
Crocker, F. B., and Arendt, M. Electric Motors..... . 8vo, *2 50
Crocker, F. B., and Wheeler, S. S. The Management of Electrical Machinery . . 12mo, *1 00
Cross, C. F., Bevan, E. J., and Sindall, R. W. Wood Pulp and Its Applications. (Westminster Series.) 8vo, *2 00
Crosskey, L. R. Elementary Perspective .. 8vo, 1 00
Crosskey, L. R., and Thaw, J. Advanced Perspective . 8vo, 1 50
Culley, J. L. Theory of Arches. (Science Series No. 87.) . 16mo, 0 50

Dadourian, H. M. Analytical Mechanics 12mo, *3 00
Danby, A. Natural Rock Asphalts and Bitumens 8vo, *2 50
Davenport, C. The Book. (Westminster Series.).. . .... 8vo, *2 00
Davies, D. C. Metalliferous Minerals and Mining.. .... 8vo, 5 00
—— Earthy Minerals and Mining 8vo, 5 00
Davies, E. H. Machinery for Metalliferous Mines ... 8vo, 8 00
Davies, F. H. Electric Power and Traction.. 8vo, *2 00
—— Foundations and Machinery Fixing. (Installation Manual Series.) 16mo, *1 00
Dawson, P. Electric Traction on Railways...... . . 8vo, *9 00
Day, C. The Indicator and Its Diagrams 12mo, *2 00
Deerr, N. Sugar and the Sugar Cane . 8vo, *8 00
Deite, C. Manual of Soapmaking. Trans. by S. T. King. 4to, *5 00
De la Coux, H. The Industrial Uses of Water. Trans. by A. Morris. 8vo, *4 50
Del Mar, W. A. Electric Power Conductors . 8vo, *2 00
Denny, G. A. Deep-level Mines of the Rand. . . . 4to, *10 00
—— Diamond Drilling for Gold .. . *5 00
De Roos, J. D. C. Linkages. (Science Series No. 47.) 16mo, 0 50
Derr, W. L. Block Signal Operation . .... Oblong 12mo, *1 50
—— Maintenance-of-Way Engineering (*In Preparation.*)
Desaint, A. Three Hundred Shades and How to Mix Them 8vo, *10 00
De Varona, A. Sewer Gases. (Science Series No. 55.) 16mo, 0 50
Devey, R. G. Mill and Factory Wiring. (Installation Manuals Series.) 12mo, *1 00
Dibdin, W. J. Public Lighting by Gas and Electricity 8vo, *8 00
—— Purification of Sewage and Water 8vo, 6 50
Dichmann, Carl. Basic Open-Hearth Steel Process 12mo, *3 50
Dieterich, K. Analysis of Resins, Balsams, and Gum Resins 8vo, *3 00
Dinger, Lieut. H. C. Care and Operation of Naval Machinery 12mo, *2 00
Dixon, D. B. Machinist's and Steam Engineer's Practical Calculator. 16mo, morocco, 1 25
Doble, W. A. Power Plant Construction on the Pacific Coast (*In Press.*)
Dommett, W. E. Motor Car Mechanism .12mo, *1 25
Dorr, B. F. The Surveyor's Guide and Pocket Table-book. 16mo, morocco, 2 00
Down, P. B. Handy Copper Wire Table ..16mo, *1 00

Draper, C. H. Elementary Text-book of Light, Heat and Sound 12mo, 1 00
—— Heat and the Principles of Thermo-dynamics 12mo, *2 00
Dubbel, H. High Power Gas Engines.................. (In Press.)
Duckwall, E. W. Canning and Preserving of Food Products 8vo, *5 00
Dumesny, P., and Noyer, J. Wood Products, Distillates, and Extracts. 8vo, *4 50
Duncan, W. G., and Penman, D. The Electrical Equipment of Collieries. 8vo, *4 00
Dunstan, A. E., and Thole, F. B. T. Textbook of Practical Chemistry. 12mo, *1 40
Duthie, A. L. Decorative Glass Processes. (Westminster Series.) 8vo, *2 00
Dwight, H. B. Transmission Line Formulas 8vo, *2 00
Dyson, S. S. Practical Testing of Raw Materials 8vo, *5 00
Dyson, S. S., and Clarkson, S. S. Chemical Works 8vo, *7 50

Eccles, R. G., and Duckwall, E. W. Food Preservatives 8vo, paper, 0 50
Eck, J. Light, Radiation and Illumination. Trans. by Paul Hogner, 8vo, *2 50
Eddy, H. T. Maximum Stresses under Concentrated Loads 8vo, 1 50
Edelman, P. Inventions and Patents 12mo. (In Press.)
Edgcumbe, K. Industrial Electrical Measuring Instruments 8vo, *2 50
Edler, R. Switches and Switchgear. Trans. by Ph. Laubach 8vo, *4 00
Eissler, M. The Metallurgy of Gold .. 8vo, 7 50
—— The Hydrometallurgy of Copper . 8vo, *4 50
—— The Metallurgy of Silver 8vo, 4 00
—— The Metallurgy of Argentiferous Lead 8vo, 5 00
—— A Handbook on Modern Explosives 8vo, 5 00
Ekin, T. C. Water Pipe and Sewage Discharge Diagrams folio, *3 00
Eliot, C. W., and Storer, F. H. Compendious Manual of Qualitative Chemical Analysis 12mo, *1 25
Ellis, C. Hydrogenation of Oils 8vo. (In Press.)
Ellis, G. Modern Technical Drawing . . . 8vo, *2 00
Ennis, Wm. D. Linseed Oil and Other Seed Oils 8vo, *4 00
—— Applied Thermodynamics 8vo, *4 50
—— Flying Machines To-day 12mo, *4 50
—— Vapors for Heat Engines 12mo, *1 00
Erfurt, J. Dyeing of Paper Pulp. Trans. by J. Hubner 8vo, *7 50
Ermen, W. F. A. Materials Used in Sizing 8vo, *2 00
Evans, C. A. Macadamized Roads (In Press.)
Ewing, A. J. Magnetic Induction in Iron 8vo, *4 00

Fairie, J. Notes on Lead Ores . 12mo, *1 00
—— Notes on Pottery Clays . . 12mo, *1 50
Fairley, W., and Andre, Geo. J. Ventilation of Coal Mines. (Science Series No. 58.) 16mo, 0 50
Fairweather, W. C. Foreign and Colonial Patent Laws 8vo, *3 00
Fanning, J. T. Hydraulic and Water-supply Engineering 8vo, *5 00
Fauth, P. The Moon in Modern Astronomy. Trans. by J. McCabe. 8vo, *2 00

Fay, I. W. The Coal-tar Colors. 8vo, *4 00
Fernbach, R. L. Glue and Gelatine 8vo, *3 00
—— Chemical Aspects of Silk Manufacture . 12mo, *1 00
Fischer, E. The Preparation of Organic Compounds. Trans. by R. V. Stanford . . . 12mo, *1 25
Fish, J. C. L. Lettering of Working Drawings Oblong 8vo, 1 00
Fisher, H. K. C., and Darby, W. C. Submarine Cable Testing . 8vo, *3 50
Fleischmann, W. The Book of the Dairy. Trans. by C. M. Aikman. 8vo, 4 00
Fleming, J. A. The Alternate-current Transformer. Two Volumes. 8vo.
Vol. I. The Induction of Electric Currents *5 00
Vol. II. The Utilization of Induced Currents . *5 00
Fleming, J. A. Propagation of Electric Currents . 8vo, *3 00
—— Centenary of the Electrical Current 8vo, *0 50
—— Electric Lamps and Electric Lighting 8vo, *3 00
—— Electrical Laboratory Notes and Forms . . 4to, *5 00
—— A Handbook for the Electrical Laboratory and Testing Room. Two Volumes . . . . 8vo, each, *5 00
Fleury, P. Preparation and Uses of White Zinc Paints . . 8vo, *2 50
Fleury, H. The Calculus Without Limits or Infinitesimals. Trans. by C. O. Mailloux. . . . . (*In Press.*)
Flynn, P. J. Flow of Water. (Science Series No. 84.) . . 12mo, 0 50
—— Hydraulic Tables. (Science Series No. 66.) . . . 16mo, 0 50
Foley, N. British and American Customary and Metric Measures folio, *3 00
Forgie, J. Shield Tunneling . 8vo. (*In Press.*)
Foster, H. A. Electrical Engineers' Pocket-book. (*Seventh Edition.*) 12mo, leather, 5 00
—— Engineering Valuation of Public Utilities and Factories 8vo, *3 00
—— Handbook of Electrical Cost Data . . . . . . 8vo (*In Press.*)
Foster, Gen. J. G. Submarine Blasting in Boston (Mass.) Harbor 4to, 3 50
Fowle, F. F. Overhead Transmission Line Crossings 12mo, *1 50
—— The Solution of Alternating Current Problems . 8vo (*In Press.*)
Fox, W. G. Transition Curves. (Science Series No. 110.) 16mo, 0 50
Fox, W., and Thomas, C. W. Practical Course in Mechanical Drawing . 12mo, 1 25
Foye, J. C. Chemical Problems. (Science Series No. 69.) 16mo, 0 50
—— Handbook of Mineralogy. (Science Series No. 86.) 16mo, 0 50
Francis, J. B. Lowell Hydraulic Experiments 4to, 15 00
Franzen, H. Exercises in Gas Analysis 12mo, *1 00
Freudemacher, P. W. Electrical Mining Installations. (Installation Manuals Series.) 12mo, *1 00
Frith, J. Alternating Current Design . . . 8vo, *2 00
Fritsch, J. Manufacture of Chemical Manures. Trans. by D. Grant. 8vo, *4 00
Frye, A. I. Civil Engineers' Pocket-book 12mo, leather, *5 00
Fuller, G. W. Investigations into the Purification of the Ohio River. 4to, *10 00
Furnell, J. Paints, Colors, Oils, and Varnishes 8vo. *1 00

Gairdner, J. W. I. Earthwork . . . . 8vo (*In Press.*)

Gant, L. W. Elements of Electric Traction	8vo,	*2 50
Garcia, A. J. R. V. Spanish-English Railway Terms	8vo,	*4 50
Garforth, W. E. Rules for Recovering Coal Mines after Explosions and Fires	12mo, leather,	1 50
Gaudard, J. Foundations. (Science Series No. 34.)	16mo,	0 50
Gear, H. B., and Williams, P. F. Electric Central Station Distribution Systems	8vo,	*3 00
Geerligs, H. C. P. Cane Sugar and Its Manufacture	8vo,	*5 00
—— World's Cane Sugar Industry	8vo,	*5 00
Geikie, J. Structural and Field Geology	8vo,	*4 00
—— Mountains. Their Growth, Origin and Decay	8vo,	*4 00
—— The Antiquity of Man in Europe	8vo. *(In Press.)*	
Gerber, N. Analysis of Milk, Condensed Milk, and Infants' Milk-Food.	8vo,	1 25
Gerhard, W. P. Sanitation, Watersupply and Sewage Disposal of Country Houses	12mo,	*2 00
—— Gas Lighting (Science Series No. 111.)	16mo,	0 50
—— Household Wastes. (Science Series No. 97.)	16mo,	0 50
—— House Drainage. (Science Series No. 63.)	16mo,	0 50
Gerhard, W. P. Sanitary Drainage of Buildings. (Science Series No. 93.)	16mo,	0 50
Gerhardi, C. W. H. Electricity Meters	8vo,	*4 00
Geschwind, L. Manufacture of Alum and Sulphates. Trans. by C. Salter	8vo,	*5 00
Gibbs, W. E. Lighting by Acetylene	12mo,	*1 50
—— Physics of Solids and Fluids. (Carnegie Technical School's Text-books.)		*1 50
Gibson, A. H. Hydraulics and Its Application	8vo,	*5 00
—— Water Hammer in Hydraulic Pipe Lines	12mo,	*2 00
Gilbreth, F. B. Motion Study	12mo,	*2 00
—— Primer of Scientific Management	12mo,	*1 00
Gillmore, Gen. Q. A. Limes, Hydraulic Cements and Mortars	8vo,	4 00
—— Roads, Streets, and Pavements	12mo,	2 00
Golding, H. A. The Theta-Phi Diagram	12mo,	*1 25
Goldschmidt, R. Alternating Current Commutator Motor	8vo,	*3 00
Goodchild, W. Precious Stones. (Westminster Series.)	8vo,	*2 00
Goodeve, T. M. Textbook on the Steam-engine	12mo,	2 00
Gore, G. Electrolytic Separation of Metals	8vo,	*3 50
Gould, E. S. Arithmetic of the Steam-engine	12mo,	1 00
—— Calculus. (Science Series No. 112.)	16mo,	0 50
—— High Masonry Dams. (Science Series No. 22.)	16mo,	0 50
—— Practical Hydrostatics and Hydrostatic Formulas. (Science Series No. 117.)	16mo,	0 50
Gratacap, L. P. A Popular Guide to Minerals	8vo,	*3 00
Gray, J. Electrical Influence Machines	12mo,	2 00
—— Marine Boiler Design	12mo,	*1 25
Greenhill, G. Dynamics of Mechanical Flight	8vo,	*2 50
Greenwood, E. Classified Guide to Technical and Commercial Books.	8vo,	*3 00
Gregorius, R. Mineral Waxes. Trans. by C. Salter	12mo,	*3 00
Griffiths, A. B. A Treatise on Manures	12mo,	3 00
—— Dental Metallurgy	8vo,	*3 50

Gross, E. Hops .8vo,	*4 50
Grossman, J. Ammonia and Its Compounds 12mo,	*1 25
Groth, L. A. Welding and Cutting Metals by Gases or Electricity. (Westminster Series) 8vo,	*2 00
Grover, F. Modern Gas and Oil Engines 8vo,	*2 00
Gruner, A. Power-loom Weaving 8vo,	*3 00
Güldner, Hugo. Internal Combustion Engines. Trans. by H. Diederichs. 4to,	*10 00
Gunther, C. O. Integration 12mo,	*1 25
Gurden, R. L. Traverse Tables folio, half morocco,	*7 50
Guy, A. E. Experiments on the Flexure of Beams 8vo,	*1 25
Haeder, H. Handbook on the Steam-engine. Trans. by H. H. P. Powles 12mo,	3 00
Hainbach, R. Pottery Decoration. Trans. by C. Salter 12mo,	*3 00
Haenig, A. Emery and Emery Industry .8vo,	*2 50
Hale, W. J. Calculations of General Chemistry 12mo,	*1 00
Hall, C. H. Chemistry of Paints and Paint Vehicles 12mo,	*2 00
Hall, G. L. Elementary Theory of Alternate Current Working 8vo,	*1 50
Hall, R. H. Governors and Governing Mechanism .12mo,	*2 00
Hall, W. S. Elements of the Differential and Integral Calculus 8vo,	*2 25
—— Descriptive Geometry 8vo volume and a 4to atlas,	*3 50
Haller, G. F., and Cunningham, E. T. The Tesla Coil .12mo,	*1 25
Halsey, F. A. Slide Valve Gears 12mo,	1 50
—— The Use of the Slide Rule. (Science Series No. 114.) 16mo,	0 50
—— Worm and Spiral Gearing. (Science Series No. 116.) 16mo,	0 50
Hamilton, W. G. Useful Information for Railway Men 16mo,	1 00
Hammer, W. J. Radium and Other Radio-active Substances 8vo,	*1 00
Hancock, H. Textbook of Mechanics and Hydrostatics 8vo,	1 50
Hardy, E. Elementary Principles of Graphic Statics 12mo,	*1 50
Harris, S. M. Practical Topographical Surveying .(*In Press*)	
Harrison, W. B. The Mechanics' Tool-book .12mo,	1 50
Hart, J. W. External Plumbing Work 8vo,	*3 00
—— Hints to Plumbers on Joint Wiping 8vo,	*3 00
—— Principles of Hot Water Supply 8vo,	*3 00
—— Sanitary Plumbing and Drainage 8vo,	*3 00
Haskins, C. H. The Galvanometer and Its Uses .16mo,	1 50
Hatt, J. A. H. The Colorist square 12mo,	*1 50
Hausbrand, E. Drying by Means of Air and Steam. Trans. by A. C. Wright 12mo,	*2 00
—— Evaporating, Condensing and Cooling Apparatus. Trans. by A. C. Wright 8vo,	*5 00
Hausner, A. Manufacture of Preserved Foods and Sweetmeats. Trans. by A. Morris and H. Robson 8vo,	*3 00
Hawke, W. H. Premier Cipher Telegraphic Code 4to,	*5 00
—— 100,000 Words Supplement to the Premier Code 4to,	*5 00
Hawkesworth, J. Graphical Handbook for Reinforced Concrete Design. 4to,	*2 50
Hay, A. Alternating Currents 8vo,	*2 50
—— Electrical Distributing Networks and Distributing Lines 8vo,	*3 50
—— Continuous Current Engineering 8vo,	*2 50

Hayes, H. V. Public Utilities, Their Cost New and Depreciation...8vo, *2 00
Heap, Major D. P. Electrical Appliances 8vo, 2 00
Heather, H. J. S. Electrical Engineering 8vo, *3 50
Heaviside, O. Electromagnetic Theory. Vols. I and II 8vo, each, *5 00
Vol. III. ... 8vo, *7 50
Heck, R. C. H. The Steam Engine and Turbine............. 8vo, *5 00
—— Steam-Engine and Other Steam Motors. Two Volumes.
Vol. I. Thermodynamics and the Mechanics . 8vo, *3 50
Vol. II. Form, Construction, and Working........... 8vo, *5 00
—— Notes on Elementary Kinematics................ 8vo, boards, *1 00
—— Graphics of Machine Forces...... .... 8vo, boards, *1 00
Hedges, K. Modern Lightning Conductors. 8vo, 3 00
Heermann, P. Dyers' Materials. Trans. by A. C. Wright 12mo, *2 50
Hellot, Macquer and D'Apligny. Art of Dyeing Wool, Silk and Cotton. 8vo, *2 00
Henrici, O. Skeleton Structures. . 8vo, 1 50
Hering, D. W. Essentials of Physics for College Students 8vo, *1 75
Hering-Shaw, A. Domestic Sanitation and Plumbing. Two Vols. 8vo, *5 00
Hering-Shaw, A. Elementary Science .. . 8vo, *2 00
Herrmann, G. The Graphical Statics of Mechanism. Trans. by A. P. Smith... . .. . 12mo, 2 00
Herzfeld, J. Testing of Yarns and Textile Fabrics .. 8vo, *3 50
Hildebrandt, A. Airships, Past and Present 8vo, *3 50
Hildenbrand, B. W. Cable-Making. (Science Series No. 32.) 16mo, 0 50
Hilditch, T. P. A Concise History of Chemistry 12mo, *1 25
Hill, J. W. The Purification of Public Water Supplies. New Edition. (*In Press*)
—— Interpretation of Water Analysis . (*In Press*)
Hill, M. J. M. The Theory of Proportion 8vo, *2 50
Hiroi, I. Plate Girder Construction. (Science Series No 95.) 16mo, 0 50
—— Statically-Indeterminate Stresses. 12mo, *2 00
Hirshfeld, C. F. Engineering Thermodynamics. (Science Series No. 45.) 16mo, 0 50
Hobart, H. M. Heavy Electrical Engineering 8vo, *4 50
—— Design of Static Transformers 12mo, *2 00
—— Electricity 8vo, *2 00
—— Electric Trains 8vo, *2 50
Hobart, H. M. Electric Propulsion of Ships 8vo, *2 00
Hobart, J. F. Hard Soldering, Soft Soldering and Brazing 12mo, *1 00
Hobbs, W. R. P. The Arithmetic of Electrical Measurements 12mo, 0 50
Hoff, J. N. Paint and Varnish Facts and Formulas 12mo, *1 50
Hole, W. The Distribution of Gas 8vo, *7 50
Holley, A. L. Railway Practice folio, 12 00
Holmes, A. B. The Electric Light Popularly Explained 12mo, paper, 0 50
Hopkins, N. M. Experimental Electrochemistry 8vo, *3 00
—— Model Engines and Small Boats ... 12mo, 1 25
Hopkinson, J., Shoolbred, J. N, and Day, R. E. Dynamic Electricity. (Science Series No. 71.) 16mo, 0 50
Horner, J. Metal Turning .. . 12mo, 1 50
—— Modern Ironfounding.. . . . .12mo, *2 50
—— Plating and Boiler Making... ....8vo, 3 00
Houghton, C. E. The Elements of Mechanics of Materials......12mo, *2 00

Houllevigue, L. The Evolution of the Sciences 8vo, *2 00
Houstoun, R. A. Studies in Light Production 12mo, 2 00
Howe, G. Mathematics for the Practical Man 12mo, *1 25
Howorth, J. Repairing and Riveting Glass, China and Earthenware. 8vo, paper, *0 50
Hubbard, E. The Utilization of Wood-waste 8vo, *2 50
Hübner, J. Bleaching and Dyeing of Vegetable and Fibrous Materials. (Outlines of Industrial Chemistry.) 8vo, *5 00
Hudson, O. F. Iron and Steel. (Outlines of Industrial Chemistry.).8vo, *2 00
Humper, W. Calculation of Strains in Girders 12mo, 2 50
Humphreys, A. C. The Business Features of Engineering Practice .8vo, *1 25
Hunter, A. Bridge Work 8vo. (*In Press.*)
Hurst, G. H. Handbook of the Theory of Color 8vo, *2 50
—— Dictionary of Chemicals and Raw Products 8vo, *3 00
—— Lubricating Oils, Fats and Greases . 8vo, *4 00
—— Soaps 8vo, *5 00
Hurst, G. H., and Simmons, W. H Textile Soaps and Oils 8vo, *2 50
Hurst, H. E., and Lattey, R. T. Text-book of Physics . 8vo, *3 00
—— Also published in three parts.
Part I. Dynamics and Heat. *1 25
Part II. Sound and Light. *1 25
Part III. Magnetism and Electricity. . *1 50
Hutchinson, R. W., Jr. Long Distance Electric Power Transmission. 12mo, *3 00
Hutchinson, R. W., Jr, and Thomas, W. A. Electricity in Mining 12mo, (*In Press.*)
Hutchinson, W. B. Patents and How to Make Money Out of Them. 12mo, 1 25
Hutton, W. S. Steam-boiler Construction 8vo, 6 00
—— Practical Engineer's Handbook . . 8vo, 7 00
—— The Works' Manager's Handbook 8vo, 6 00
Hyde, E. W. Skew Arches. (Science Series No. 15.) 16mo, 0 50
Hyde, F. S. Solvents, Oils, Gums, Waxes 8vo, *2 00

Induction Coils. (Science Series No. 53.) 16mo, 0 50
Ingham, A. E. Gearing. A practical treatise (*In Press.*)
Ingle, H. Manual of Agricultural Chemistry 8vo, *3 00
Inness, C. H. Problems in Machine Design . 12mo, *2 00
—— Air Compressors and Blowing Engines . . 12mo, *2 00
—— Centrifugal Pumps . 12mo, *2 00
—— The Fan 12mo, *2 00
Isherwood, B. F. Engineering Precedents for Steam Machinery 8vo, 2 50
Ivatts, E. B. Railway Management at Stations. . . 8vo, *2 50

Jacob, A., and Gould, E. S. On the Designing and Construction of Storage Reservoirs. (Science Series No. 6). 16mo, 0 50
Jannettaz, E. Guide to the Determination of Rocks. Trans. by G. W. Plympton 12mo, 1 50
Jehl, F. Manufacture of Carbons . . 8vo, *4 00
Jennings, A. S. Commercial Paints and Painting. (Westminster Series.) 8vo, *2 00

Jennison, F. H. The Manufacture of Lake Pigments. 8vo, *3 00
Jepson, G. Cams and the Principles of their Construction 8vo, *1 50
—— Mechanical Drawing 8vo (*In Preparation*)
Jockin, W. Arithmetic of the Gold and Silversmith. 12mo, *1 00
Johnson, J. H. Arc Lamps and Accessory Apparatus. (Installation Manuals Series.) 12mo, *0 75
Johnson, T. M. Ship Wiring and Fitting. (Installation Manuals Series.) 12mo, *0 75
Johnson, W. H. The Cultivation and Preparation of Para Rubber 8vo, *3 00
Johnson, W. McA. The Metallurgy of Nickel (*In Preparation*)
Johnston, J. F. W., and Cameron, C. Elements of Agricultural Chemistry and Geology . . 12mo, 2 60
Joly, J. Radioactivity and Geology. 12mo, *3 00
Jones, H. C. Electrical Nature of Matter and Radioactivity 12mo, *2 00
—— New Era in Chemistry 12mo, *2 00
Jones, M. W. Testing Raw Materials Used in Paint 12mo, *2 00
Jones, L., and Scard, F. I. Manufacture of Cane Sugar 8vo, *5 00
Jordan, L. C. Practical Railway Spiral 12mo, leather, *1 50
Joynson, F. H. Designing and Construction of Machine Gearing 8vo, 2 00
Juptner, H. F. V. Siderology: The Science of Iron 8vo, *5 00

Kansas City Bridge . . 4to, 6 00
Kapp, G. Alternate Current Machinery. (Science Series No. 96.). 16mo, 0 50
Keim, A. W. Prevention of Dampness in Buildings 8vo, *2 00
Keller, S. S. Mathematics for Engineering Students. 12mo, half leather
Algebra and Trigonometry, with a Chapter on Vectors *1 75
Special Algebra Edition *1 00
Plane and Solid Geometry *1 25
Analytical Geometry and Calculus *2 00
Kelsey, W. R. Continuous-current Dynamos and Motors 8vo, *2 50
Kemble, W. T., and Underhill, C. R. The Periodic Law and the Hydrogen Spectrum 8vo, paper, *0 50
Kemp, J. F. Handbook of Rocks 8vo, *1 50
Kendall, E. Twelve Figure Cipher Code 4to, *12 50
Kennedy, A. B. W., and Thurston, R. H. Kinematics of Machinery. (Science Series No. 54.) 16mo, 0 50
Kennedy, A. B. W., Unwin, W. C., and Idell, F. E. Compressed Air. (Science Series No. 106.) 16mo, 0 50
Kennedy, R. Modern Engines and Power Generators. Six Volumes. 4to, 15 00
Single Volumes each, 3 00
—— Electrical Installations. Five Volumes 4to, 15 00
Single Volumes .. ... each, 3 50
—— Flying Machines; Practice and Design. 12mo, *2 00
—— Principles of Aeroplane Construction . . 8vo, *1 50
Kennelly, A. E. Electro-dynamic Machinery 8vo, 1 50
Kent, W. Strength of Materials. (Science Series No. 41.) 16mo, 0 50
Kershaw, J. B. C. Fuel, Water and Gas Analysis. . .. 8vo, *2 50
—— Electrometallurgy. (Westminster Series.) 8vo, *2 00
—— The Electric Furnace in Iron and Steel Production 12mo, *1 50
—— Electro-Thermal Methods of Iron and Steel Production 8vo, *3 00

Kinzbrunner, C. Alternate Current Windings	8vo,	*1 50
—— Continuous Current Armatures	8vo,	*1 50
—— Testing of Alternating Current Machines	8vo,	*2 00
Kirkaldy, W. G. David Kirkaldy's System of Mechanical Testing	4to,	10 00
Kirkbride, J. Engraving for Illustration	8vo,	*1 50
Kirkwood, J. P. Filtration of River Waters	4to,	7 50
Kirschke, A. Gas and Oil Engines	12mo,	*1 25
Klein, J. F. Design of a High-speed Steam-engine	8vo,	*5 00
—— Physical Significance of Entropy	8vo,	*1 50
Kleinhans, F. B. Boiler Construction	8vo,	3 00
Knight, R.-Adm. A. M. Modern Seamanship	8vo,	*7 50
Half morocco		*9 00
Knox, J. Physico-Chemical Calculations	12mo,	*1 00
—— Fixation of Atmospheric Nitrogen. (Chemical Monographs, No. 4.)	12mo.	(*In Press.*)
Knox, W. F. Logarithm Tables	(*In Preparation.*)	
Knott, C. G., and Mackay, J. S. Practical Mathematics	8vo,	2 00
Koester, F. Steam-Electric Power Plants	4to,	*5 00
—— Hydroelectric Developments and Engineering	4to,	*5 00
Koller, T. The Utilization of Waste Products	8vo,	*3 50
—— Cosmetics	8vo,	*2 50
Kremann, R. Application of the Physico-Chemical Theory to Technical Processes and Manufacturing Methods. Trans. by H. E. Potts	8vo,	*3 00
Kretchmar, K. Yarn and Warp Sizing.	8vo,	*4 00
Lallier, E. V. Elementary Manual of the Steam Engine	12mo,	*2 00
Lambert, T. Lead and Its Compounds	8vo,	*3 50
—— Bone Products and Manures	8vo,	*3 00
Lamborn, L. L. Cottonseed Products	8vo,	*3 00
—— Modern Soaps, Candles, and Glycerin	8vo,	*7 50
Lamprecht, R. Recovery Work After Pit Fires. Trans. by C. Salter	8vo,	*4 00
Lancaster, M. Electric Heating, Cooking, Cleaning	12mo.	(*In Press.*)
Lanchester, F. W. Aerial Flight. Two Volumes. 8vo.		
Vol. I. Aerodynamics		*6 00
—— Aerial Flight. Vol. II. Aerodonetics		*6 00
Larner, E. T. Principles of Alternating Currents	12mo.	*1 25
Larrabee, C. S. Cipher and Secret Letter and Telegraphic Code	16mo,	0 60
La Rue, B. F. Swing Bridges. (Science Series No. 107.)	16mo,	0 50
Lassar-Cohn. Dr. Modern Scientific Chemistry. Trans. by M. M. Pattison Muir	12mo,	*2 00
Latimer, L. H., Field, C. J., and Howell, J. W. Incandescent Electric Lighting. (Science Series No. 57.)	16mo,	0 50
Latta, M. N. Handbook of American Gas-Engineering Practice	8vo,	*4 50
—— American Producer Gas Practice	4to,	*6 00
Lawson, W. R. British Railways. A Financial and Commercial Survey	8vo,	2 00
Leask, A. R. Breakdowns at Sea	12mo,	2 00
—— Refrigerating Machinery	12mo,	2 00
Lecky, S. T. S. "Wrinkles" in Practical Navigation	8vo,	*8 00

Le Doux, M. Ice-Making Machines. (Science Series No. 46.) 16mo, 0 50
Leeds, C. C. Mechanical Drawing for Trade Schools .oblong 4to,
High School Edition *1 25
Machinery Trades Edition *2.00
Lefêvre, L. Architectural Pottery. Trans. by H. K. Bird and W. M. Binns 4to, *7 50
Lehner, S. Ink Manufacture. Trans. by A. Morris and H. Robson 8vo, *2 50
Lemstrom, S. Electricity in Agriculture and Horticulture 8vo, *1 50
Letts, E. A. Fundamental Problems in Chemistry 8vo, *2 00
Le Van, W. B. Steam-Engine Indicator. (Science Series No. 78.) 16mo, 0 50
Lewes, V. B. Liquid and Gaseous Fuels. (Westminster Series.) 8vo, *2 00
—— Carbonization of Coal 8vo, *3 00
Lewis, L. P. Railway Signal Engineering 8vo, *3 50
Lieber, B. F. Lieber's Standard Telegraphic Code . 8vo, *10 00
—— Code. German Edition 8vo, *10 00
—— —— Spanish Edition 8vo, *10 00
—— —— French Edition 8vo, *10 00
—— Terminal Index 8vo, *2 50
—— Lieber's Appendix .... folio, *15 00
—— —— Handy Tables 4to, *2 50
—— Bankers and Stockbrokers' Code and Merchants and Shippers' Blank Tables 8vo, *15 00
—— 100,000,000 Combination Code 8vo, *10 00
—— Engineering Code 8vo, *12 50
Livermore, V. P., and Williams, J. How to Become a Competent Motorman ... .12mo, *1 00
Liversedge, A. J. Commercial Engineering 8vo, *3 00
Livingstone, R. Design and Construction of Commutators 8vo, *2 25
—— Mechanical Design and Construction of Generators 8vo. (*In Press.*)
Lobben, P. Machinists' and Draftsmen's Handbook 8vo, 2 50
Lockwood, T. D. Electricity, Magnetism, and Electro-telegraph 8vo, 2 50
Lockwood, T. D. Electrical Measurement and the Galvanometer. 12mo, 0 75
Lodge, O. J. Elementary Mechanics 12mo, 1 50
—— Signalling Across Space without Wires 8vo, *2 00
Loewenstein, L. C., and Crissey, C. P. Centrifugal Pumps . . . *4 50
Lord, R. T. Decorative and Fancy Fabrics 8vo, *3 50
Loring, A. E. A Handbook of the Electromagnetic Telegraph . 16mo 0 50
—— Handbook. (Science Series No. 39.) 16mo, 0 50
Low, D. A. Applied Mechanics (Elementary) 16mo, 0 80
Lubschez, B. J. Perspective . ... .12mo, *1 50
Lucke, C. E. Gas Engine Design 8vo, *3 00
—— Power Plants: Design, Efficiency, and Power Costs. 2 vols. (*In Preparation.*)
Lunge, G. Coal-tar and Ammonia. Two Volumes . .8vo, *15 00
—— Manufacture of Sulphuric Acid and Alkali. Four Volumes 8vo,
Vol. I. Sulphuric Acid. In three parts . . *18 00
Vol. II. Salt Cake, Hydrochloric Acid and Leblanc Soda. In two parts *15.00

Lunge, G. Manufacture of Sulphuric Acid and Alkali.
Vol. III. Ammonia Soda *10 00
Vol. IV. Electrolytic Methods . . (In Press)
—— Technical Chemists' Handbook . . 12mo, leather, *3 50
—— Technical Methods of Chemical Analysis. Trans. by C. A. Keane in collaboration with the corps of specialists.
Vol. I. In two parts . . 8vo, *15 00
Vol. II. In two parts 8vo, *18 00
Vol. III. . . . . . (In Preparation)
Lupton, A., Parr, G. D. A., and Perkin, H. Electricity as Applied to Mining . . . 8vo, *4 50
Luquer, L. M. Minerals in Rock Sections 8vo, *1 50

Macewen, H. A. Food Inspection . . 8vo, *2 50
Mackenzie, N. F. Notes on Irrigation Works 8vo, *2 50
Mackie, J. How to Make a Woolen Mill Pay . 8vo, *2 00
Mackrow, C. Naval Architect's and Shipbuilder's Pocket-book. 16mo, leather, 5 00
Maguire, Wm R. Domestic Sanitary Drainage and Plumbing 8vo, 4 00
Mallet, A. Compound Engines. Trans. by R. R. Buel. (Science Series No. 10.) 16mo,
Mansfield, A. N. Electro-magnets. (Science Series No. 64.) . 16mo, 0 50
Marks, E. C. R. Construction of Cranes and Lifting Machinery 12mo, *1 50
—— Construction and Working of Pumps 12mo, *1 50
—— Manufacture of Iron and Steel Tubes . . . 12mo, *2 00
—— Mechanical Engineering Materials . . 12mo, *1 00
Marks, G. C. Hydraulic Power Engineering 8vo, 3 50
—— Inventions, Patents and Designs . . . 12mo, *1 00
Marlow, T. G. Drying Machinery and Practice 8vo, *5 00
Marsh, C. F. Concise Treatise on Reinforced Concrete . . .8vo, *2 50
—— Reinforced Concrete Compression Member Diagram. Mounted on Cloth Boards *1 50
Marsh, C. F., and Dunn, W. Manual of Reinforced Concrete and Concrete Block Construction . 16mo, morocco, *2 50
Marshall, W. J., and Sankey, H. R. Gas Engines. (Westminster Series.) 8vo, *2 00
Martin, G. Triumphs and Wonders of Modern Chemistry 8vo, *2 00
Martin, N. Properties and Design of Reinforced Concrete . 12mo, *2 50
Massie, W. W., and Underhill, C. R. Wireless Telegraphy and Telephony 12mo, *1 00
Matheson, D. Australian Saw-Miller's Log and Timber Ready Reckoner. 12mo, leather, 1 50
Mathot, R. E. Internal Combustion Engines . . 8vo, *6 00
Maurice, W. Electric Blasting Apparatus and Explosives 8vo, *3 50
—— Shot Firer's Guide . 8vo, *1 50
Maxwell, J. C. Matter and Motion. (Science Series No. 36.). 16mo, 0 50
Maxwell, W. H., and Brown, J. T. Encyclopedia of Muncipal and Sanitary Engineering 4to, *10 00
Mayer, A. M. Lecture Notes on Physics 8vo, 2 00
McCullough, R. S. Mechanical Theory of Heat 8vo, 3 50

McIntosh, J. G. Technology of Sugar 8vo, *4 50
—— Industrial Alcohol 8vo, *3 00
—— Manufacture of Varnishes and Kindred Industries. Three Volumes. 8vo.
Vol. I. Oil Crushing, Refining and Boiling. . *3 50
Vol. II. Varnish Materials and Oil Varnish Making . *4 00
Vol. III. Spirit Varnishes and Materials *4 50
McKnight, J. D., and Brown, A. W. Marine Multitubular Boilers . *1 50
McMaster, J. B. Bridge and Tunnel Centres. (Science Series No. 20.) 16mo, 0 50
McMechen, F. L. Tests for Ores, Minerals and Metals 12mo, *1 00
McPherson, J. A. Water-works Distribution .. 8vo, 2 50
Melick, C. W. Dairy Laboratory Guide 12mo, *1 25
Merck, E. Chemical Reagents, Their Purity and Tests. Trans. by H. E. Schenck . . 8vo, 1 00
Merivale, J. H. Notes and Formulae for Mining Students 12mo, 1 50
Merritt, Wm. H. Field Testing for Gold and Silver 16mo, leather, 1 50
Messer, W. A. Railway Permanent Way. 8vo (*In Press.*)
Meyer, J. G. A., and Pecker, C. G. Mechanical Drawing and Machine Design 4to, 5 00
Michell, S. Mine Drainage 8vo, 10 00
Mierzinski, S. Waterproofing of Fabrics. Trans. by A. Morris and H. Robson 8vo, *2 50
Miller, G. A. Determinants. (Science Series No 105.) 16mo,
Milroy, M. E. W. Home Lace-making 12mo, *1 00
Minifie, W. Mechanical Drawing 8vo, *4 00
Mitchell, C. A. Mineral and Aerated Waters. 8vo, *3 00
Mitchell, C. A., and Prideaux, R. M. Fibres Used in Textile and Allied Industries . 8vo, *3 00
Mitchell, C. F., and G. A. Building Construction and Drawing. 12mo.
Elementary Course *1 50
Advanced Course *2 50
Monckton, C. C. F. Radiotelegraphy. (Westminster Series.) 8vo, *2 00
Monteverde, R. D. Vest Pocket Glossary of English-Spanish, Spanish-English Technical Terms 64mo, leather, *1 00
Montgomery, J. H. Electric Wiring Specifications (*In Press.*)
Moore, E. C. S. New Tables for the Complete Solution of Ganguillet and Kutter's Formula 8vo, *5 00
Morecroft, J. H., and Hehre, F. W. Short Course in Electrical Testing. 8vo, *1 50
Moreing, C. A., and Neal, T. New General and Mining Telegraph Code. 8vo, *5 00
Morgan, A. P. Wireless Telegraph Apparatus for Amateurs 12mo, *1 50
Moses, A. J. The Characters of Crystals 8vo, *2 00
—— and Parsons, C. L. Elements of Mineralogy 8vo, *2 50
Moss, S.A. Elements of Gas Engine Design.(Science Series No.121.)16mo, 0 50
—— The Lay-out of Corliss Valve Gears. (Science Series No. 119.) 16mo, 0 50
Mulford, A. C. Boundaries and Landmarks 12mo, *1 00
Mullin, J. P. Modern Moulding and Pattern-making . . . 12mo, 2 50

Munby, A. E. Chemistry and Physics of Building Materials. (Westminster Series.) 8vo, *2 00
Murphy, J. G. Practical Mining 16mo, 1 00
Murphy, W. S. Textile Industries. Eight Volumes *20 00
Sold separately, each, *3 00
Murray, J. A. Soils and Manures. (Westminster Series.) 8vo, *2 00

Naquet, A. Legal Chemistry 12mo, 2 00
Nasmith, J. The Student's Cotton Spinning 8vo, 3 00
—— Recent Cotton Mill Construction 12mo, 2 00
Neave, G. B., and Heilbron, I. M. Identification of Organic Compounds. 12mo, *1 25
Neilson, R. M. Aeroplane Patents 8vo, *2 00
Nerz, F. Searchlights. Trans. by C. Rodgers 8vo, *3 00
Neuberger, H., and Noalhat, H. Technology of Petroleum. Trans. by J. G. McIntosh 8vo, *10 00
Newall, J. W. Drawing, Sizing and Cutting Bevel-gears 8vo, 1 50
Nicol, G. Ship Construction and Calculations 8vo, *4 50
Nipher, F. E. Theory of Magnetic Measurements 12mo, 1 00
Nisbet, H. Grammar of Textile Design 8vo, *3 00
Nolan, H. The Telescope. (Science Series No. 51.) 16mo, 0 50
Noll, A. How to Wire Buildings 12mo, 1 50
North, H. B. Laboratory Experiments in General Chemistry 12mo, *1 00
Nugent, E. Treatise on Optics 12mo, 1 50

O'Connor, H. The Gas Engineer's Pocketbook 12mo, leather, 3 50
—— Petrol Air Gas 12mo, *0 75
Ohm, G. S., and Lockwood, T. D. Galvanic Circuit. Translated by William Francis. (Science Series No. 102.) 16mo, 0 50
Olsen, J. C. Text-book of Quantitative Chemical Analysis 8vo, *4 00
Olsson, A. Motor Control, in Turret Turning and Gun Elevating. (U. S. Navy Electrical Series, No. 1.) 12mo, paper, *0 50
Ormsby, M. T. M. Surveying 12mo, 1 50
Oudin, M. A. Standard Polyphase Apparatus and Systems. 8vo, *3 00
Owen, D. Recent Physical Research 8vo, *1 50

Pakes, W. C. C., and Nankivell, A. T. The Science of Hygiene 8vo, *1 75
Palaz, A. Industrial Photometry. Trans. by G. W. Patterson, Jr 8vo, *4 00
Pamely, C. Colliery Manager's Handbook 8vo, *10 00
Parker, P. A. M. The Control of Water 8vo, *5 00
Parr, G. D. A. Electrical Engineering Measuring Instruments 8vo, *3 50
Parry, E. J. Chemistry of Essential Oils and Artificial Perfumes 8vo, *5 00
—— Foods and Drugs. Two Volumes. 8vo,
Vol. I. Chemical and Microscopical Analysis of Foods and Drugs. *7 50
Vol. II. Sale of Food and Drugs Act *3 00
—— and Coste, J. H. Chemistry of Pigments 8vo, *4 50
Parry, L. A. Risk and Dangers of Various Occupations 8vo, *3 00
Parshall, H. F., and Hobart, H. M. Armature Windings 4to, *7 50
—— Electric Railway Engineering 4to, *10 00
—— and Parry, E. Electrical Equipment of Tramways. (*In Press*.)

Parsons, S. J. **Malleable Cast Iron**... 8vo, *2 50
Partington, J. R. Higher Mathematics for Chemical Students .12mo, *2 00
—— Textbook of Thermodynamics 8vo, *4 00
Passmore, A. C. Technical Terms Used in Architecture 8vo, *3 50
Patchell, W. H. Electric Power in Mines.......... 8vo, *4 00
Paterson, G. W. L. Wiring Calculations....................12mo, *2 00
Patterson, D. The Color Printing of Carpet Yarns 8vo, *3 50
—— Color Matching on Textiles 8vo, *3 00
—— The Science of Color Mixing 8vo, *3 00
Paulding, C. P. Condensation of Steam in Covered and Bare Pipes 8vo, *2 00
—— Transmission of Heat through Cold-storage Insulation.... 12mo, *1 00
Payne, D. W. Iron Founders' Handbook. .. ..(*In Press.*)
Peddie, R. A. Engineering and Metallurgical Books .. 12mo, *1 50
Peirce, B. System of Analytic Mechanics .. 4to, 10 00
Pendred, V. The Railway Locomotive. (Westminster Series.) 8vo, *2 00
Perkin, F. M. Practical Methods of Inorganic Chemistry 12mo, *1 00
Perrigo, O. E. Change Gear Devices 8vo, 1 00
Perrine, F. A. C. Conductors for Electrical Distribution . . 8vo, *3 50
Perry, J. Applied Mechanics 8vo, *2 50
Petit, G. White Lead and Zinc White Paints . 8vo, *1 50
Petit, R. How to Build an Aeroplane. Trans. by T. O'B. Hubbard, and J. H. Ledeboer . 8vo, *1 50
Pettit, Lieut. J. S. Graphic Processes. (Science Series No. 76.).. 16mo, 0 50
Philbrick, P. H. Beams and Girders. (Science Series No. 88.) .16mo,
Phillips, J. Engineering Chemistry 8vo, *4 50
—— Gold Assaying 8vo, *2 50
—— Dangerous Goods....... .... 8vo, 3 50
Phin, J. Seven Follies of Science ... 12mo, *1 25
Pickworth, C. N. The Indicator Handbook. Two Volumes 12mo, each, 1 50
—— Logarithms for Beginners . ... 12mo. boards, 0 50
—— The Slide Rule 12mo, 1 00
Plattner's Manual of Blow-pipe Analysis. Eighth Edition, revised. Trans. by H. B. Cornwall .. . 8vo, *4 00
Plympton, G. W. The Aneroid Barometer. (Science Series No. 35.) 16mo, 0 50
—— How to become an Engineer (Science Series No. 100.)..... 16mo, 0 50
—— Van Nostrand's Table Book. (Science Series No. 104.).......16mo, 0 50
Pochet, M. L. Steam Injectors. Translated from the French. (Science Series No. 29.).. ....16mo, 0 50
Pocket Logarithms to Four Places. (Science Series No. 65.) . 16mo, 0 50
leather, 1 00
Polleyn, F. Dressings and Finishings for Textile Fabrics. 8vo, *3 00
Pope, F. G. Organic Chemistry . ... .12mo, *2 25
Pope, F. L. Modern Practice of the Electric Telegraph . 8vo, 1 50
Popplewell, W. C. Elementary Treatise on Heat and Heat Engines 12mo, *3 00
—— Prevention of Smoke 8vo, *3 50
—— Strength of Materials 8vo, *1 75
Porritt, B. D. The Chemistry of Rubber. (Chemical Monographs, No. 3.) 12mo, *0 75
Porter, J. R. Helicopter Flying Machine......................12mo, *1 25
Potter, T. Concrete.. .... 8vo, *3 00

Potts, H. E. Chemistry of the Rubber Industry. (Outlines of Industrial Chemistry)....8vo, *2 00
Practical Compounding of Oils, Tallow and Grease.... 8vo, *3 50
Practical Iron Founding 12mo, 1 50
Pratt, K. Boiler Draught.... 12mo, *1 25
Pray, T., Jr. Twenty Years with the Indicator.... 8vo, 2 50
—— Steam Tables and Engine Constant 8vo, 2 00
Preece, W. H. Electric Lamps.... (*In Press*)
Prelini, C. Earth and Rock Excavation 8vo, *3 00
—— Graphical Determination of Earth Slopes.... 8vo, *2 00
—— Tunneling. New Edition.... 8vo, *3 00
—— Dredging. A Practical Treatise.... 8vo, *3 00
Prescott, A. B. Organic Analysis 8vo, 5 00
Prescott, A. B., and Johnson, O. C. Qualitative Chemical Analysis 8vo, *3 50
Prescott, A. B., and Sullivan, E. C. First Book in Qualitative Chemistry. 12mo, *1 50
Prideaux, E. B. R. Problems in Physical Chemistry.... 8vo, *2 00
Pritchard, O. G. The Manufacture of Electric-light Carbons 8vo, paper, *0 60
Pullen, W. W. F. Application of Graphic Methods to the Design of Structures 12mo, *2 50
—— Injectors: Theory, Construction and Working 12mo, *1 50
Pulsifer, W. H. Notes for a History of Lead 8vo, 4 00
Purchase, W. R. Masonry.... 12mo, *3 00
Putsch, A. Gas and Coal-dust Firing 8vo, *3 00
Pynchon, T. R. Introduction to Chemical Physics 8vo, 3 00

Rafter G. W. Mechanics of Ventilation. (Science Series No. 33.). 16mo, 0 50
—— Potable Water. (Science Series No. 103.) 16mo, 0 50
—— Treatment of Septic Sewage. (Science Series No. 118.) 16mo, 0 50
Rafter, G. W., and Baker, M. N. Sewage Disposal in the United States. 4to, *6 00
Raikes, H. P. Sewage Disposal Works 8vo, *4 00
Randall, P. M. Quartz Operator's Handbook. 12mo, 2 00
Randau, P. Enamels and Enamelling 8vo, *4 00
Rankine, W. J. M. Applied Mechanics 8vo, 5 00
—— Civil Engineering 8vo, 6 50
—— Machinery and Millwork 8vo, 5 00
—— The Steam-engine and Other Prime Movers. 8vo, 5 00
—— Useful Rules and Tables 8vo, 4 00
Rankine, W. J. M., and Bamber, E. F. A Mechanical Text-book... 8vo, 3 50
Raphael, F. C. Localization of Faults in Electric Light and Power Mains. 8vo, *3 00
Rasch, E. Electric Arc Phenomena. Trans. by K. Tornberg 8vo, *2 00
Rathbone, R. L. B. Simple Jewellery.... 8vo, *2 00
Rateau, A. Flow of Steam through Nozzles and Orifices. Trans. by H. B. Brydon 8vo *1 50
Rausenberger, F. The Theory of the Recoil of Guns 8vo, *4 50
Rautenstrauch, W. Notes on the Elements of Machine Design. 8vo, boards, *1 50
Rautenstrauch, W., and Williams, J. T. Machine Drafting and Empirical Design.

Part I. Machine Drafting 8vo, *1 25
Part II. Empirical Design .... (*In Preparation*)
Raymond, E. B. Alternating Current Engineering..... . 12mo, *2 50
Rayner, H. Silk Throwing and Waste Silk Spinning . . 8vo, *2 50
Recipes for the Color, Paint, Varnish, Oil, Soap and Drysaltery Trades 8vo, *3 50
Recipes for Flint Glass Making 12mo, *4 50
Redfern, J. B., and Savin, J. Bells, Telephones (Installation Manuals Series.) . 16mo, *0 50
Redgrove, H. S. Experimental Mensuration . . . 12mo, *1 25
Redwood, B. Petroleum. (Science Series No. 92.) .. 16mo, 0 50
Reed, S. Turbines Applied to Marine Propulsion *5 00
Reed's Engineers' Handbook 8vo, *5 00
—— Key to the Nineteenth Edition of Reed's Engineers' Handbook 8vo, *3 00
—— Useful Hints to Sea-going Engineers 12mo, 1 50
—— Marine Boilers 12mo, 2 00
—— Guide to the Use of the Slide Valve . 12mo, *1 60
Reinhardt, C. W. Lettering for Draftsmen, Engineers, and Students. oblong 4to, boards, 1 00
—— The Technic of Mechanical Drafting . . oblong 4to, boards, *1 00
Reiser, F. Hardening and Tempering of Steel. Trans. by A. Morris and H. Robson 12mo, *2 50
Reiser, N. Faults in the Manufacture of Woolen Goods. Trans. by A. Morris and H. Robson 8vo, *2 50
—— Spinning and Weaving Calculations 8vo, *5 00
Renwick, W. G. Marble and Marble Working. 8vo, 5 00
Reynolds, O., and Idell, F. E. Triple Expansion Engines. (Science Series No. 99.).. . . . 16mo, 0 50
Rhead, G. F. Simple Structural Woodwork 12mo, *1 00
Rhodes, H. J. Art of Lithography 8vo, 3 50
Rice, J. M., and Johnson, W. W. A New Method of Obtaining the Differential of Functions 12mo, 0 50
Richards, W. A. Forging of Iron and Steel . .. ...(*In Press*)
Richards, W. A., and North, H. B. Manual of Cement Testing 12mo, *1 50
Richardson, J. The Modern Steam Engine . 8vo, *3 50
Richardson, S. S. Magnetism and Electricity. .. . 12mo, *2 00
Rideal, S. Glue and Glue Testing. . 8vo, *4 00
Rimmer, E. J. Boiler Explosions, Collapses and Mishaps 8vo, *1 75
Rings, F. Concrete in Theory and Practice 12mo, *2 50
—— Reinforced Concrete Bridges .. 4to, *5 00
Ripper, W. Course of Instruction in Machine Drawing folio, *6 00
Roberts, F. C. Figure of the Earth. (Science Series No. 79.) . 16mo, 0 50
Roberts, J., Jr. Laboratory Work in Electrical Engineering 8vo, *2 00
Robertson, L. S. Water-tube Boilers . . . 8vo, 2 00
Robinson, J. B. Architectural Composition 8vo, *2 50
Robinson, S. W. Practical Treatise on the Teeth of Wheels. (Science Series No. 24.) . 16mo, 0 50
—— Railroad Economics. (Science Series No. 59.). .16mo, 0 50
—— Wrought Iron Bridge Members. (Science Series No. 60.).... 16mo, 0 50
Robson, J. H. Machine Drawing and Sketching 8vo, *1 50
Roebling, J. A. Long and Short Span Railway Bridges ....folio, 25 00

Rogers, A. A Laboratory Guide of Industrial Chemistry. . . .. .12mo, *1 50
Rogers, A., and Aubert, A. B. Industrial Chemistry.. .. .. 8vo, *5 00
Rogers, F. Magnetism of Iron Vessels. (Science Series No. 30.) 16mo, 0 50
Rohland, P. Colloidal and Crystalloidal State of Matter. Trans. by W. J. Britland and H. E. Potts 12mo, *1 25
Rollins, W. Notes on X-Light .. . 8vo, *5 00
Rollinson, C. Alphabets . . . . . . Oblong, 12mo, *1 00
Rose, J. The Pattern-makers' Assistant . 8vo, 2 50
—— Key to Engines and Engine-running . 12mo, 2 50
Rose, T. K. The Precious Metals. (Westminster Series.) . 8vo, *2 00
Rosenhain, W. Glass Manufacture. (Westminster Series.) . 8vo, *2 00
Ross, W. A. Blowpipe in Chemistry and Metallurgy 12mo, *2 00
Roth. Physical Chemistry . . 8vo, *2 00
Rouillion, L. The Economics of Manual Training 8vo, 2 00
Rowan, F. J. Practical Physics of the Modern Steam-boiler 8vo, *3 00
—— and Idell, F. E. Boiler Incrustation and Corrosion. (Science Series No. 27.) 16mo, 0 50
Roxburgh, W. General Foundry Practice . 8vo, *3 50
Ruhmer, E. Wireless Telephony. Trans. by J. Erskine-Murray 8vo, *3 50
Russell, A. Theory of Electric Cables and Networks 8vo, *3 00

Sabine, R. History and Progress of the Electric Telegraph 12mo, 1 25
Saeltzer, A. Treatise on Acoustics 12mo, 1 00
Sanford, P. G. Nitro-explosives 8vo, *4 00
Saunders, C. H. Handbook of Practical Mechanics 16mo, 1 00
leather, 1 25
Saunnier, C. Watchmaker's Handbook 12mo, 3 00
Sayers, H. M. Brakes for Tram Cars 8vo, *1 25
Scheele, C. W. Chemical Essays 8vo, *2 00
Scheithauer, W. Shale Oils and Tars 8vo, *3 50
Schellen, H. Magneto-electric and Dynamo-electric Machines 8vo, 5 00
Scherer, R. Casein. Trans. by C. Salter. 8vo, *3 00
Schidrowitz, P. Rubber, Its Production and Industrial Uses 8vo, *5 00
Schindler, K. Iron and Steel Construction Works. 12mo, *1 25
Schmall, C. N. First Course in Analytic Geometry, Plane and Solid. 12mo, half leather, *1 75
Schmall, C. N., and Shack, S. M. Elements of Plane Geometry. 12mo, *1 25
Schmeer, L. Flow of Water . 8vo, *3 00
Schumann, F. A Manual of Heating and Ventilation 12mo, leather, 1 50
Schwarz, E. H. L. Causal Geology . 8vo, *2 50
Schweizer, V. Distillation of Resins . 8vo, *3 50
Scott, W. W. Qualitative Analysis. A Laboratory Manual 8vo, *1 50
Scribner, J. M. Engineers' and Mechanics' Companion .16mo, leather, 1 50
Scudder, H. Electrical Conductivity and Ionization Constants of Organic Compounds 8vo, *3 00
Searle, A. B. Modern Brickmaking 8vo, *5 00
—— Cement, Concrete and Bricks....... .... 8vo, *3 00
Searle, G. M. "Sumners' Method." Condensed and Improved. (Science Series No. 124.) 16mo, 0 50
Seaton, A. E. Manual of Marine Engineering 8vo 8 00

Seaton, A. E., and Rounthwaite, H. M. Pocket-book of Marine Engineering . . . 16mo, leather, 3 00
Seeligmann, T., Torrilhon, G. L., and Falconnet, H. India Rubber and Gutta Percha. Trans. by J. G. McIntosh . . . 8vo, *5 00
Seidell, A. Solubilities of Inorganic and Organic Substances . 8vo, *3 00
Sellew, W. H. Steel Rails . . . 4to, *12 50
Senter, G. Outlines of Physical Chemistry . . . 12mo, *1 75
—— Text-book of Inorganic Chemistry . . . 12mo, *1 75
Sever, G. F. Electric Engineering Experiments . . . 8vo, boards, *1 00
Sever, G. F., and Townsend, F. Laboratory and Factory Tests in Electrical Engineering . . . 8vo, *2 50
Sewall, C. H. Wireless Telegraphy . . . 8vo, *2 00
—— Lessons in Telegraphy . . . 12mo, *1 00
Sewell, T. Elements of Electrical Engineering 8vo, *3 00
—— The Construction of Dynamos . 8vo, *3 00
Sexton, A. H. Fuel and Refractory Materials . 12mo, *2 50
—— Chemistry of the Materials of Engineering . 12mo, *2 50
—— Alloys (Non-Ferrous) . . . 8vo, *3 00
—— The Metallurgy of Iron and Steel . . . 8vo, *6 50
Seymour, A. Practical Lithography . . . 8vo, *2 50
—— Modern Printing Inks . . . 8vo, *2 00
Shaw, Henry S. H. Mechanical Integrators. (Science Series No. 83.) 16mo, 0 50
Shaw, S. History of the Staffordshire Potteries . . . 8vo, 2 00
—— Chemistry of Compounds Used in Porcelain Manufacture 8vo, *5 00
Shaw, W. N. Forecasting Weather . . . 8vo, 3 50
Sheldon, S., and Hausmann, E. Direct Current Machines . 12mo, *2 50
—— Alternating Current Machines . . . 12mo, *2 50
Sheldon, S., and Hausmann, E. Electric Traction and Transmission Engineering . . . 12mo, *2 50
Sheriff, F. F. Oil Merchants' Manual . . . 12mo, *3 50
Shields, J. E. Notes on Engineering Construction . 12mo, 1 50
Shreve, S. H. Strength of Bridges and Roofs . . 8vo, 3 50
Shunk, W. F. The Field Engineer 12mo, morocco, 2 50
Simmons, W. H., and Appleton, H. A. Handbook of Soap Manufacture, 8vo, *3 00
Simmons, W. H., and Mitchell, C. A. Edible Fats and Oils 8vo, *3 00
Simms, F. W. The Principles and Practice of Levelling 8vo, 2 50
—— Practical Tunneling . 8vo, 7 50
Simpson, G. The Naval Constructor . . . 12mo, morocco, *5 00
Simpson, W. Foundations . . . 8vo. (*In Press*)
Sinclair, A. Development of the Locomotive Engine . . 8vo, half leather, 5 00
—— Twentieth Century Locomotive . . . 8vo, half leather, *5 00
Sindall, R. W., and Bacon, W. N. The Testing of Wood Pulp 8vo, *2 50
Sindall, R. W. Manufacture of Paper. (Westminster Series.) 8vo, *2 00
Sloane, T. O'C. Elementary Electrical Calculations 12mo, *2 00
Smallwood, J. C. Mechanical Laboratory Methods . . 12mo, leather, *2 50
Smith, C. A. M. Handbook of Testing, MATERIALS . . 8vo, *2 50
Smith, C. A. M., and Warren, A. G. New Steam Tables . . . 8vo, *1 25

Smith, C. F. Practical Alternating Currents and Testing . 8vo, *2 50
—— Practical Testing of Dynamos and Motors 8vo, *2 00
Smith, F. E. Handbook of General Instruction for Mechanics. 12mo, 1 50
Smith, H. G. Minerals and the Microscope . .
Smith, J. C. Manufacture of Paint . .. 8vo, *3 00
—— Paint and Painting Defects .
Smith, R. H. Principles of Machine Work .. 12mo, *3 00
—— Elements of Machine Work . 12mo, *2 00
Smith, W. Chemistry of Hat Manufacturing 12mo, *3 00
Snell, A. T. Electric Motive Power 8vo, *4 00
Snow, W. G. Pocketbook of Steam Heating and Ventilation. (*In Press.*)
Snow, W. G., and Nolan, T. Ventilation of Buildings. (Science Series No. 5.) 16mo, 0 50
Soddy, F. Radioactivity 8vo, *3 00
Solomon, M. Electric Lamps. (Westminster Series.) 8vo, *2 00
Sothern, J. W. The Marine Steam Turbine 8vo, *5 00
—— Verbal Notes and Sketches for Marine Engineers 8vo, *5 00
Southcombe, J. E. Chemistry of the Oil Industries. (Outlines of Industrial Chemistry.) 8vo, *3 00
Soxhlet, D. H. Dyeing and Staining Marble. Trans. by A. Morris and H. Robson . 8vo, *2 50
Spang, H. W. A Practical Treatise on Lightning Protection 12mo, 1 00
Spangenburg, L. Fatigue of Metals. Translated by S. H. Shreve. (Science Series No. 23.) 16mo, 0 50
Specht, G. J., Hardy, A. S., McMaster, J. B., and Walling. Topographical Surveying. (Science Series No. 72.) 16mo, 0 50
Speyers, C. L. Text-book of Physical Chemistry 8vo, *2 25
Sprague, E. H. Hydraulics 12mo, 1 25
Stahl, A. W. Transmission of Power. (Science Series No. 28.) 16mo,
Stahl, A. W., and Woods, A. T. Elementary Mechanism 12mo, *2 00
Staley, C., and Pierson, G. S. The Separate System of Sewerage 8vo, *3 00
Standage, H. C. Leatherworkers' Manual . 8vo, *3 50
—— Sealing Waxes, Wafers, and Other Adhesives 8vo, *2 00
—— Agglutinants of all Kinds for all Purposes 12mo, *3 50
Stanley, H. Practical Applied Physics ... .(*In Press.*)
Stansbie, J. H. Iron and Steel. (Westminster Series.) 8vo, *2 00
Steadman, F. M. Unit Photography and Actinometry . (*In Press.*)
Stecher, G. E. Cork. Its Origin and Industrial Uses..........12mo, 1 00
Steinman, D. B. Suspension Bridges and Cantilevers. (Science Series No. 127.) 0 50
Stevens, H. P. Paper Mill Chemist 16mo, *2 50
Stevens, J. S. Precision of Measurements (*In Press.*)
Stevenson, J. L. Blast-Furnace Calculations 12mo, leather, *2 00
Stewart, A. Modern Polyphase Machinery 12mo, *2 00
Stewart, G. Modern Steam Traps 12mo, *1 25
Stiles, A. Tables for Field Engineers 12mo, 1 00
Stillman, P. Steam-engine Indicator 12mo, 1 00
Stodola, A. Steam Turbines. Trans. by L. C. Loewenstein 8vo, *5 00
Stone, H. The Timbers of Commerce . . . 8vo, 3 50
Stone, Gen. R. New Roads and Road Laws . .. .12mo, 1 00

Stopes, M. Ancient Plants 8vo, *2 00
—— The Study of Plant Life 8vo, *2 00
Stumpf, Prof. Una-Flow of Steam Engine . 4to, *3 50
Sudborough, J. J., and James, T. C. Practical Organic Chemistry. 12mo, *2 00
Suffling, E. R. Treatise on the Art of Glass Painting 8vo, *3 50
Swan, K. Patents, Designs and Trade Marks. (Westminster Series.). 8vo, *2 00
Swinburne, J., Wordingham, C. H., and Martin, T. C. Electric Currents. (Science Series No. 109.) 16mo, 0 50
Swoope, C. W. Lessons in Practical Electricity 12mo, *2 00

Tailfer, L. Bleaching Linen and Cotton Yarn and Fabrics 8vo, *5 00
Tate, J. S. Surcharged and Different Forms of Retaining-walls. (Science Series No. 7.) 16mo, 0 50
Taylor, E. N. Small Water Supplies . 12mo, *2 00
Templeton, W. Practical Mechanic's Workshop Companion. 12mo, morocco, 2 00
Terry, H. L. India Rubber and its Manufacture. (Westminster Series.) 8vo, *2 00
Thayer, H. R. Structural Design. 8vo.
  Vol. I. Elements of Structural Design . . *2 00
  Vol. II. Design of Simple Structures (*In Preparation.*)
  Vol. III. Design of Advanced Structures (*In Preparation.*)
Thiess, J. B., and Joy, G. A. Toll Telephone Practice 8vo, *3 50
Thom, C., and Jones, W. H. Telegraphic Connections. oblong, 12mo, 1 50
Thomas, C. W. Paper-makers' Handbook (*In Press.*)
Thompson, A. B. Oil Fields of Russia 4to, *7 50
—— Petroleum Mining and Oil Field Development 8vo, *5 00
Thompson, S. P. Dynamo Electric Machines. (Science Series No. 75.) 16mo, 0 50
Thompson, W. P. Handbook of Patent Law of All Countries 16mo, 1 50
Thomson, G. S. Milk and Cream Testing 12mo, *1 75
—— Modern Sanitary Engineering, House Drainage, etc 8vo, *3 00
Thornley, T. Cotton Combing Machines 8vo, *3 00
—— Cotton Waste 8vo, *3 00
—— Cotton Spinning. 8vo.
  First Year . *1 50
  Second Year . *2 50
  Third Year *2 50
Thurso, J. W. Modern Turbine Practice 8vo, *4 00
Tidy, C. Meymott. Treatment of Sewage. (Science Series No. 94.) 16mo, 0 50
Tillmans, J. Water Purification and Sewage Disposal. Trans. by Hugh S. Taylor 8vo, *2 00
Tenney, E. H. Test Methods for Steam Power Plants (*In Press.*)
Tinney, W. H. Gold-mining Machinery 8vo, *3 00
Titherley, A. W. Laboratory Course of Organic Chemistry 8vo, *2 00
Toch, M. Chemistry and Technology of Mixed Paints 8vo, *3 00
—— Materials for Permanent Painting 12mo, *2 00
—— Chemistry and Technology of Mixed Paints. (In two volumes.) (*In Press.*)

Todd, J., and Whall, W. B. Practical Seamanship...............8vo, *7 50
Tonge, J. Coal. (Westminster Series.) 8vo, *2 00
Townsend, F. Alternating Current Engineering.... .... . 8vo, boards, *0 75
Townsend, J. Ionization of Gases by Collision. 8vo, *1 25
Transactions of the American Institute of Chemical Engineers, 8vo.
Vol. I. 1908 . ... *6 00
Vol. II. 1909 .... *6 00
Vol. III. 1910 .... *6 00
Vol. IV. 1911 .. .. *6 00
Vol. V. 1912 . . *6 00
Traverse Tables. (Science Series No. 115.) . 16mo, 0 50
morocco, 1 00
Treiber, E. Foundry Machinery. Trans. by C. Salter. 12mo, 1 25
Trinks, W., and Housum, C. Shaft Governors. (Science Series No. 122.)
16mo, 0 50
Trowbridge, W. P. Turbine Wheels. (Science Series No. 44.) 16mo, 0 50
Tucker, J. H. A Manual of Sugar Analysis 8vo, 3 50
Tunner, P. A. Treatise on Roll-turning. Trans. by J. B. Pearse.
8vo, text and folio atlas, 10 00
Turnbull, Jr., J., and Robinson, S. W. A Treatise on the Compound Steam-engine. (Science Series No. 8.) . 16mo,
Turrill, S. M. Elementary Course in Perspective 12mo, *1 25

Underhill, C. R. Solenoids, Electromagnets and Electromagnetic Windings . 12mo, *2 00
Underwood, N., and Sullivan, T. V. Chemistry and Technology of Printing Inks .. . . (*In Press*)
Urquhart, J. W. Electric Light Fitting 12mo, 2 00
—— Electro-plating . . . 12mo, 2 00
—— Electrotyping 12mo, 2 00
—— Electric Ship Lighting .. 12mo, 3 00
Usborne, P. O. G. Design of Simple Steel Bridges 8vo, *4 00

Vacher, F. Food Inspector's Handbook ....
Van Nostrand's Chemical Annual. Third issue 1913 .leather, 12mo, *2 50
—— Year Book of Mechanical Engineering Data....... .(*In Press*)
Van Wagenen, T. F. Manual of Hydraulic Mining . . 16mo, 1 00
Vega, Baron Von. Logarithmic Tables . . 8vo, cloth, 2 00
half morroco, 2 50
Vincent, C. Ammonia and its Compounds. Trans. by M. J. Salter 8vo, *2 00
Volk, C. Haulage and Winding Appliances 8vo, *4 00
Von Georgievics, G. Chemical Technology of Textile Fibres. Trans. by C. Salter 8vo, *4 50
—— Chemistry of Dyestuffs. Trans. by C. Salter 8vo, *4 50
Vose, G. L. Graphic Method for Solving Certain Questions in Arithmetic and Algebra (Science Series No. 16.) . 16mo, 0 50
Vosmaer, A. Ozone.. .... (*In Press*)

Wabner, R. Ventilation in Mines. Trans. by C. Salter 8vo, *4 50
Wade, E. J. Secondary Batteries. 8vo, *4 00

Wadmore, T. M. Elementary Chemical Theory	....	12mo,	*1 50
Wadsworth, C. Primary Battery Ignition	....	12mo,	*0 50
Wagner, E. Preserving Fruits, Vegetables, and Meat	.....	12mo,	*2 50
Waldram, P. J. Principles of Structural Mechanics	..	12mo,	*3 00
Walker, F. Aerial Navigation.	....	8vo,	2 00
—— Dynamo Building. (Science Series No. 98.)	. .	16mo,	0 50
Walker, F. Electric Lighting for Marine Engineers	.....	8vo,	2 00
Walker, J. Organic Chemistry for Students of Medicine	...	8vo,	*2 50
Walker, S. F. Steam Boilers, Engines and Turbines	...	8vo,	3 00
—— Refrigeration, Heating and Ventilation on Shipboard	....	12mo,	*2 00
—— Electricity in Mining	.....	8vo,	*3 50
Wallis-Tayler, A. J. Bearings and Lubrication	....	8vo,	*1 50
—— Aerial or Wire Ropeways	.....	8vo,	*3 00
—— Motor Cars	.....	8vo,	1 80
—— Motor Vehicles for Business Purposes	.....	8vo,	3 50
Wallis-Tayler, A. J. Pocket Book of Refrigeration and Ice Making		12mo,	1 50
—— Refrigeration, Cold Storage and Ice-Making	.....	8vo,	*4 50
—— Sugar Machinery	.....	12mo,	*2 00
Wanklyn, J. A. Water Analysis	.....	12mo,	2 00
Wansbrough, W. D. The A B C of the Differential Calculus	.	12mo,	*1 50
—— Slide Valves	.....	12mo,	*2 00
Waring, Jr., G. E. Sanitary Conditions. (Science Series No. 31.)		16mo,	0 50
—— Sewerage and Land Drainage	.		*6 00
Waring, Jr., G. E. Modern Methods of Sewage Disposal	.	12mo,	2 00
—— How to Drain a House	.....	12mo,	1 25
Warnes, A. R. Coal Tar Distillation	.....	8vo,	*2 50
Warren, F. D. Handbook on Reinforced Concrete	....	12mo,	*2 50
Watkins, A. Photography. (Westminster Series.)	.	8vo,	*2 00
Watson, E. P. Small Engines and Boilers	.	12mo,	1 25
Watt, A. Electro-plating and Electro-refining of Metals	......	8vo,	*4 50
—— Electro-metallurgy	.....	12mo,	1 00
—— The Art of Soap Making	.....	8vo,	3 00
—— Leather Manufacture	.....	8vo,	*4 00
—— Paper-Making	.....	8vo,	3 00
Weale, J. Dictionary of Terms Used in Architecture	....	12mo,	2 50
Weale's Scientific and Technical Series. (Complete list sent on application.)			
Weather and Weather Instruments	.....	12mo,	1 00
		paper,	0 50
Webb, H. L. Guide to the Testing of Insulated Wires and Cables		12mo,	1 00
Webber, W. H. Y. Town Gas. (Westminster Series.)	....	8vo,	*2 00
Weisbach, J. A Manual of Theoretical Mechanics	. . .	8vo,	*6 00
		sheep,	*7 50
Weisbach, J., and Herrmann, G. Mechanics of Air Machinery	...	8vo,	*3 75
Welch, W. Correct Lettering	.....	*(In Press.)*	
Weston, E. B. Loss of Head Due to Friction of Water in Pipes		12mo,	*1 50
Weymouth, F. M. Drum Armatures and Commutators	.	8vo,	*3 00
Wheatley, O. Ornamental Cement Work	.....	*(In Press.)*	
Wheeler, J. B. Art of War	.....	12mo,	1 75
—— Field Fortifications	.....	12mo,	1 75

Whipple, S. An Elementary and Practical Treatise on Bridge Building. 8vo, 3 00

White, A. T. Toothed Gearing 12mo, *1 25

White, C. H. Methods of Metallurgical Analysis. . . . . (In Press.)

Whithard, P. Illuminating and Missal Painting 12mo, 1 50

Wilcox, R. M. Cantilever Bridges. (Science Series No. 25.) 16mo, 0 50

Wilda, H. Steam Turbines. Trans. by C. Salter 12mo, 1 25

—— Cranes and Hoists. Trans. by C. Salter 12mo, 1 25

Wilkinson, H. D. Submarine Cable Laying and Repairing 8vo, *6 00

Williamson, J., and Blackadder, H. Surveying 8vo, (In Press.)

Williamson, R. S. On the Use of the Barometer . . 4to, 15 00

—— Practical Tables in Meteorology and Hypsometery . 4to, 2 50

Willson, F. N. Theoretical and Practical Graphics 4to, *4 00

Wilson, F. J., and Heilbron, I. M. Chemical Theory and Calculations. 12mo, *1 00

Wilson, J. F. Essentials of Electrical Engineering (In Press.)

Wimperis, H. E. Internal Combustion Engine . 8vo, *3 00

—— Application of Power to Road Transport . 12mo, *1 50

—— Primer of Internal Combustion Engine 12mo, *1 00

Winchell, N. H., and A. N. Elements of Optical Mineralogy 8vo, *3 50

Winkler, C., and Lunge, G. Handbook of Technical Gas-Analysis 8vo, 4 00

Winslow, A. Stadia Surveying. (Science Series No. 77.) 16mo, 0 50

Wisser, Lieut. J. P. Explosive Materials. (Science Series No. 70.) 16mo, 0 50

Wisser, Lieut. J. P. Modern Gun Cotton. (Science Series No. 89.) 16mo, 0 50

Wood, De V. Luminiferous Aether. (Science Series No. 85) 16mo, 0 50

Wood, J. K. Chemistry of Dyeing. (Chemical Monographs No. 2.) 12mo, *0 75

Worden, E. C. The Nitrocellulose Industry. Two Volumes 8vo, *10 00

—— Cellulose Acetate 8vo, (In Press.)

Wren, H. Organometallic Compounds of Zinc and Magnesium. (Chemical Monographs No. 1.) 12mo, *0 75

Wright, A. C. Analysis of Oils and Allied Substances 8vo, *3 50

—— Simple Method for Testing Painters' Materials . 8vo, *2 50

Wright, F. W. Design of a Condensing Plant 12mo, *1 50

Wright, H. E. Handy Book for Brewers 8vo, *5 00

Wright, J. Testing, Fault Finding, etc., for Wiremen. (Installation Manuals Series.) . . . 16mo, *0 50

Wright, T. W. Elements of Mechanics . . 8vo, *2 50

Wright, T. W., and Hayford, J. F. Adjustment of Observations 8vo, *3 00

Young, J. E. Electrical Testing for Telegraph Engineers 8vo, *4 00

Zahner, R. Transmission of Power. (Science Series No. 40.) 16mo,

Zeidler, J., and Lustgarten, J. Electric Arc Lamps . 8vo, *2 00

Zeuner, A. Technical Thermodynamics. Trans. by J. F. Klein. Two Volumes 8vo, *8 00

Zimmer, G. F. Mechanical Handling of Material 4to, *10 00

Zipser, J. Textile Raw Materials. Trans. by C. Salter 8vo, *5 00

Zur Nedden, F. Engineering Workshop Machines and Processes. Trans. by J. A. Davenport 8vo, *2 00